Draft Technical Memorandum

Technical Study #2: Evaluation of North Delta Migration Corridors: Yolo Bypass

Prepared for

Bay Delta Conservation Plan

Integration Team

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Executive Summary

This study evaluates the range of operations of the Fremont Weir to increase the frequency and duration of inundation of the Yolo Bypass. Lowering a channel through the Fremont Weir has the potential to significantly increase the frequency of inundation of the Yolo Bypass. The frequency of providing biologically-important flows is doubled as compared to the current configuration. Further, modeling indicates that sufficient velocities, depths, and general residence times could be achieved for biological benefits from flows >2,000-3,000 cfs.

The study also summarizes the known effects of floodplain inundation in the Yolo Bypass. Positive effects of inundation of the Yolo Bypass include providing spawning and rearing habitat to covered fish species, increased productivity in the Bypass and export of this productivity to downstream habitat that may be used by all covered fish species, improving growth rates of juvenile fall-run Chinook salmon, and upstream and downstream passage of migrating covered fish species. Negative effects of inundation include reduced water quality, predation, and stranding.

The consultant team recommends that the Integration Team to consider two scenarios: the Maximum Biological Benefit Scenario, which is geared primarily toward fish benefits with little consideration for other constraints associated with flooding the Yolo Bypass, and the Balanced Benefit Scenario, which provides major benefits to fish, but incorporates other constraints into operational ranges. In these recommendations, consideration has been given to reduce the negative effects of inundation on covered fish species. However, additional work is needed on operation and design features to further reduce or eliminate these negative effects.

<u>Maximum Biological Benefit Scenario:</u>
Timing: January 1-April 15
Duration: Any duration
Flows Rates: Any flows into Bypass
Activation: At least 17.53 ft (NAVD 88) in Sacramento River at Fremont Weir
Frequency: TBD

<u>Balanced Benefit Scenario:</u>
Timing: January 1-April 15
Duration: 30-45 days
Flow Rates: 2000-4000 cfs into Bypass
Activation: At least 33 ft (NAVD 88) in Sacramento River at Fremont Weir
Frequency: TBD

Study Objective

The primary objectives of this technical study are to: (1) evaluate the range of increased inundation frequency and duration of the Yolo Bypass as a result of modification to the Fremont Weir and operation, (2) summarize existing knowledge about the anticipated effects of these modifications on covered fish species both within the Yolo Bypass and elsewhere in the Delta and bays, (3) make recommendations to the BDCP Integration Team to facilitate discussion about further refining these operational parameters.

The Bay Delta Conservation Plan (BDCP) Habitat Restoration Technical Team has proposed a modification to the existing Fremont Weir to allow greater frequency of floodplain activation in the Yolo Bypass. Sacramento River flows over the weir, and into the Yolo Bypass, are often limited due to insufficient river stage as compared to the weir crest elevation. By constructing a low-elevation ("notched") section in the Fremont Weir, lower Sacramento River flows would be necessary to provide the Yolo Bypass with a minimum flow to flood part of the bypass area and sustain inundation to benefit multiple coverd fish species. This notched section and associated conveyance were evaluated and are described in this technical memorandum.

Frequency and Extent of Inundation of North Delta Corridors

The flow from the Sacramento River through the proposed low-elevation section of the Fremont Weir needs to be conveyed downstream to the head of Tule Canal, along the current location of the Toe Drain shown on Figure 1. Preliminary hydraulic analyses were performed along with hydrologic analysis to ascertain the effectiveness of such a modification of the Weir. This section describes the data sources and methods used to develop an assessment of the frequency and duration of Fremont Weir spills under current and proposed configurations of the Fremont Weir. The characteristics of inundation (area, depth, velocity, and travel time) within the Yolo Bypass are also assessed through the development and application of a preliminary hydraulic model.

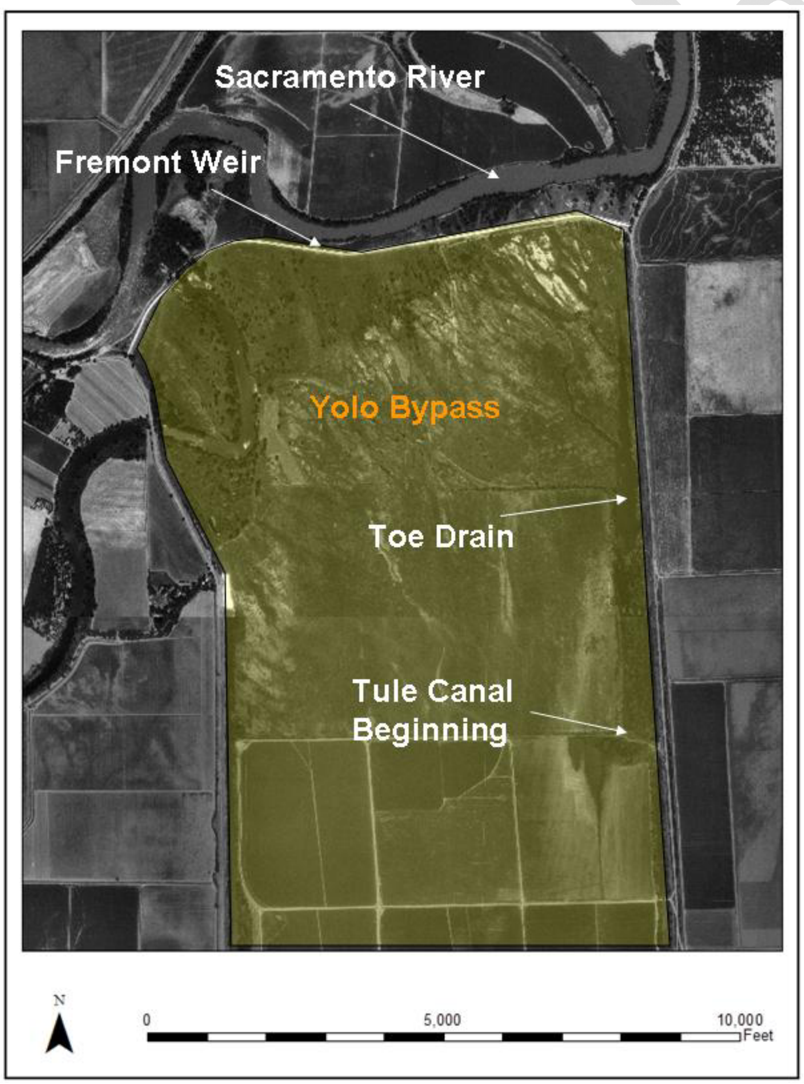

Figure 1: Aerial view of the Fremont weir and Yolo bypass location

Fremont Weir Model for Current Configuration

Data Sources

The hydrologic analysis is based on the available historical records of the Sacramento River station at Fremont (FRE), managed by the Department of Water Resources (DWR). The data types used were river stage (feet) and river discharge (cfs). The FRE station has records for daily average flows from only 1996 to present date; however, hourly data river stages and river discharge flows are available since 1984. These hourly records were used to estimate daily average values for a more complete time series. **Error! Reference source not found.** describes the stage and flow data sources used in this study. Several time series data sets were needed and the development of these time series is explained in the following section.

Table 1: Data sources used for the Fremont weir analysis

		Hourly Data			Daily Data		
Location	**Type of Data**	**Source**	**From**	**To**	**Source**	**From**	**To**
Sacramento River at Fremont	Stage (USED)	CDEC FRE	1/1/1984	Current	Computed from hourly	1/1/1984	12/31/2007
Sacramento River at Fremont	River Flow	NA	NA	NA	Computed using daily stage and DFM rating curve	1/1/1984	12/31/2007
Sacramento River at Fremont	Spill into Yolo	CDEC FRE	1/1/1984	Current	Computed from hourly	1/1/1984	12/31/2007
Sacramento River at Fremont	Spill into Yolo	NA	NA	NA	USGS 11391021	1/1/1947	9/30/1975
Sacramento River at Verona	River Flow	NA	NA	NA	USGS 11425500	10/1/1929	Current

The conversion of hourly data to daily data was performed by the HEC-DSS Vue software function that averages the hourly data in to a daily time series. **Error! Reference source not found.** shows the time series of CDEC data converted from hourly to daily time step for stage in the Sacramento River at Fremont and Fremont Weir spills into the Yolo Bypass.

The longest continuous recording station applicable to this study was found for the Sacramento River at Verona USGS gage. This time series was used to compare the current and proposed configurations of the Fremont Weir over a much longer period of record than exists directly at the Fremont Weir site.

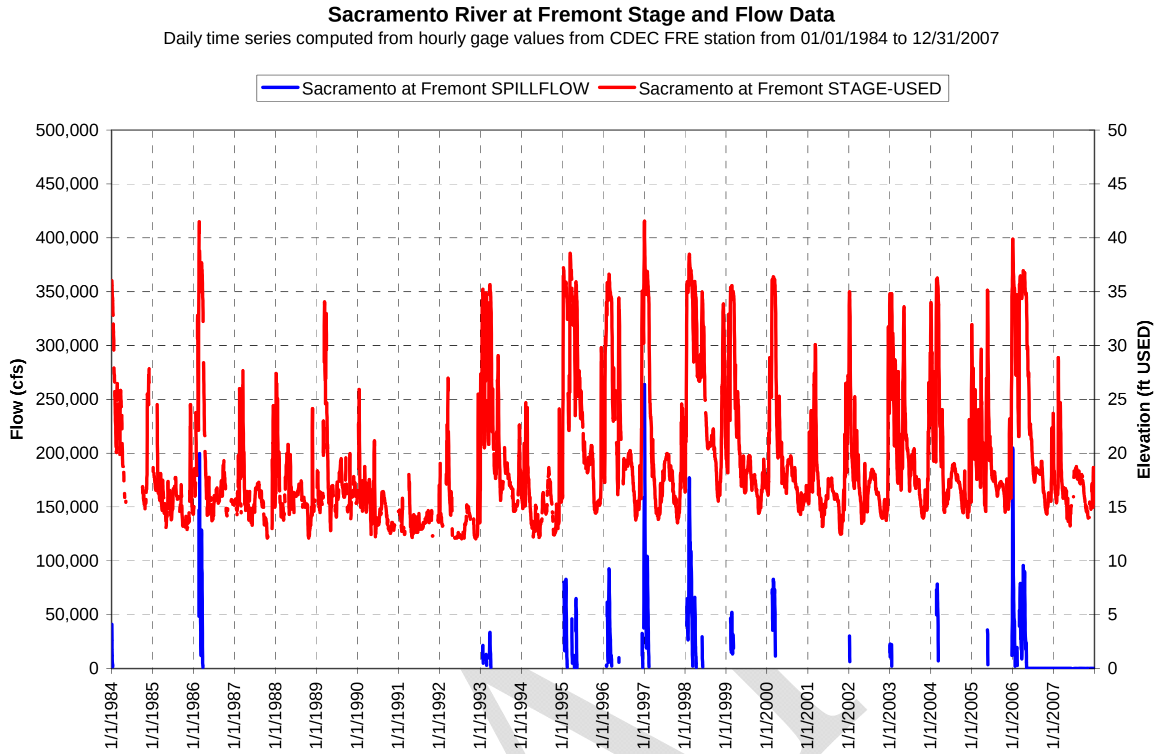

Figure 2: CDEC daily time series for stage and flow at Fremont weir. Data converted from hourly to daily

Data Development

Three time series were developed from Fremont hourly stage data and Fremont hourly spill data from CDEC. The following is a description of the process for utilizing and transforming the hourly CDEC data:

Daily Fremont Stage: Computed from HEC-DSS Vue function that averages hourly time series into daily time series.

Daily Sacramento River at Fremont flows: Computed using the daily Fremont stage time series and the synthetic rating curve for the Sacramento River at Fremont developed by the California Division of Flood Management (DFM) shown on **Error! Reference source not found.**. Given the rating curve characteristics, records below 12 ft and above 45 ft were considered as missing values.

Daily Fremont Spills: Computed from HEC-DSS Vue function that averages hourly time series into daily time series. Values described as below the rating table (BRT, code -9998) were considered as zero values and, above rating table (ART, code -9997) as missing values.

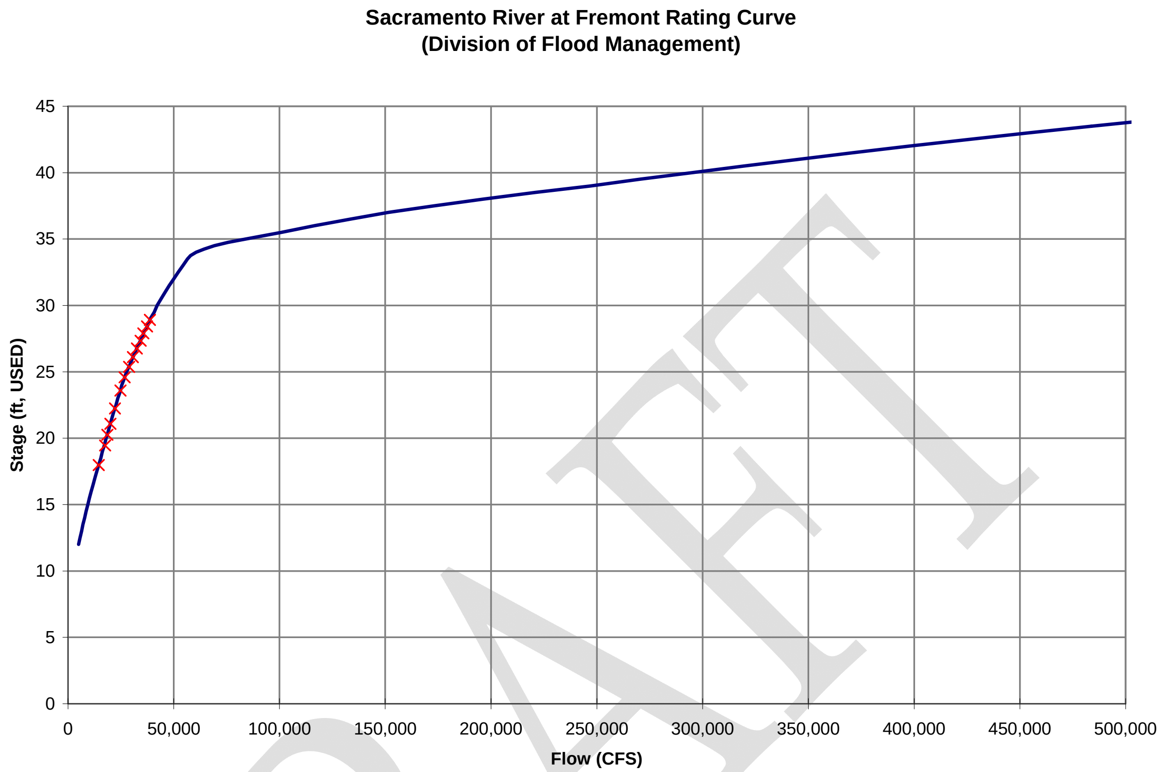

Figure 3: Sacramento River at Fremont rating curve (Source: California Division of Flood Management)

The Sacramento River at Fremont stage (converted from USED to NAVD88) time series of daily average data is presented on Figures 4, 5, and 6 with the periods in which stage exceeded the Fremont Weir crest identified. The red bars on the figures represent the consecutive number of days for which there was flow over the Weir. The figures show that 28 such events were recorded between January of 1984 and December of 2007.

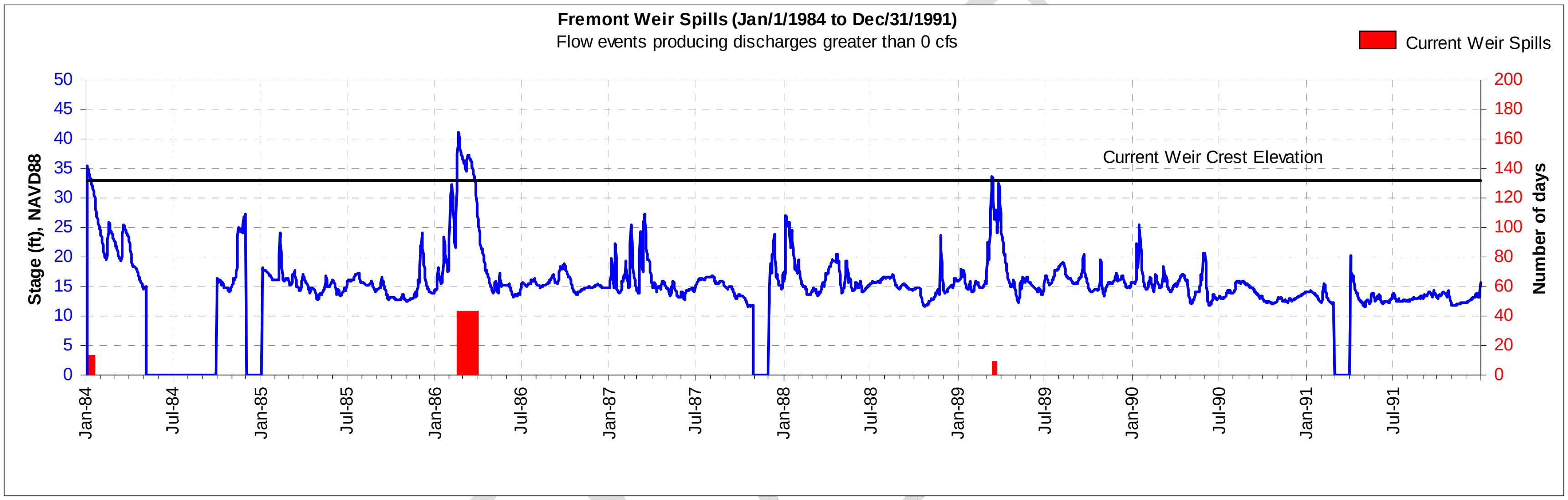
Fremont Weir Spills (Jan/1/1984 to Dec/31/1991)
Flow events producing discharges greater than 0 cfs
Current Weir Spills
Current Weir Crest Elevation
Stage (ft), NAVD88
Number of days
Jan-84
Jul-84
Jan-85
Jul-85
Jan-86
Jul-86
Jan-87
Jul-87
Jan-88
Jul-88
Jan-89
Jul-89
Jan-90
Jul-90
Jan-91
Jul-91

Figure 4: Observed Fremont Weir spills and duration (Jan 1984 to Dec 1991)

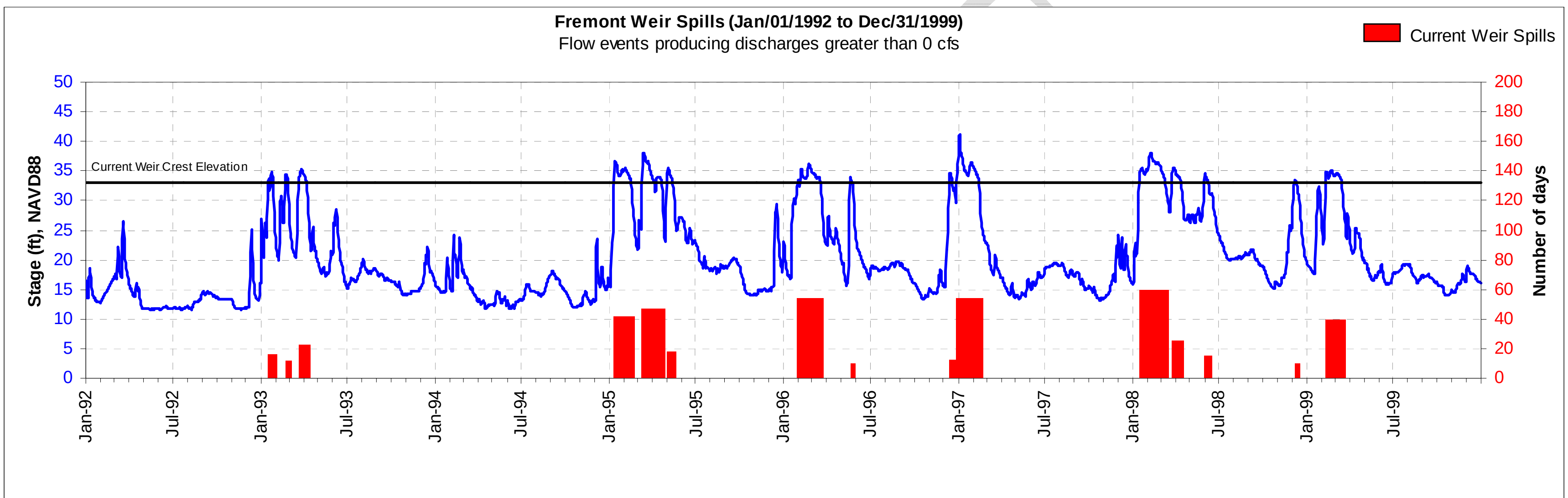

Figure 5: Observed Fremont Weir spills and duration (Jan 1992 to Dec 1999)

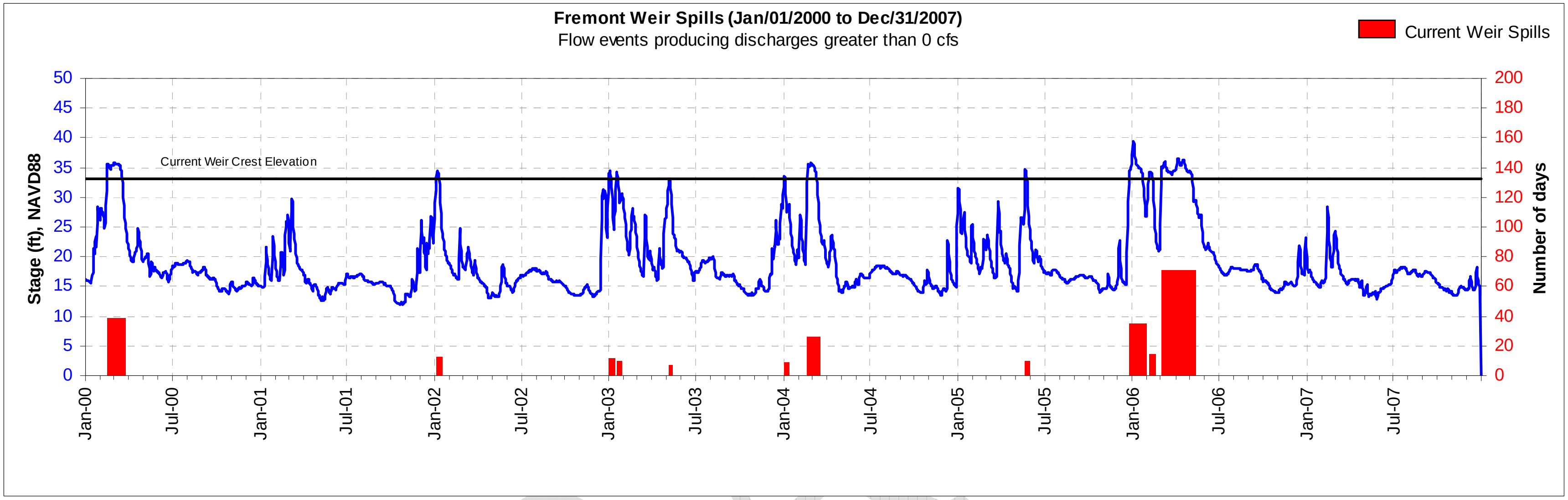

Figure 6: Observed Fremont Weir spills and duration (Jan 2000 to Dec 2007)

The computed Sacramento River at Fremont daily stage is plotted as a daily exceedance probability (Figure 7) and was to generate a similar figure for Sacramento River flows at Fremont (**Error! Reference source not found.**8). **Error! Reference source not found.** shows that under historical hydrology, the daily probability of stage greater than weir crest 33.5 ft USED is approximately 20% during January-May, but only 7% when evaluated for the entire year (i.e. stage is sufficient to generate Fremont Weir spills 20% of the days within the January – May period).

Error! Reference source not found. presents Fremont Weir daily spill probability of exceedance for the entire time series period (Jan 1984-Dec-2007). The figure shows that the Fremont Weir daily flows occur approximately 20% of the time during January through May, but only less than 6% of the time when evaluated for the entire year (January and December). The difference between the exceedance probability between stage and flows can be explained by missing gage data points or times stage was close to the crest but flows were too small to be reported.

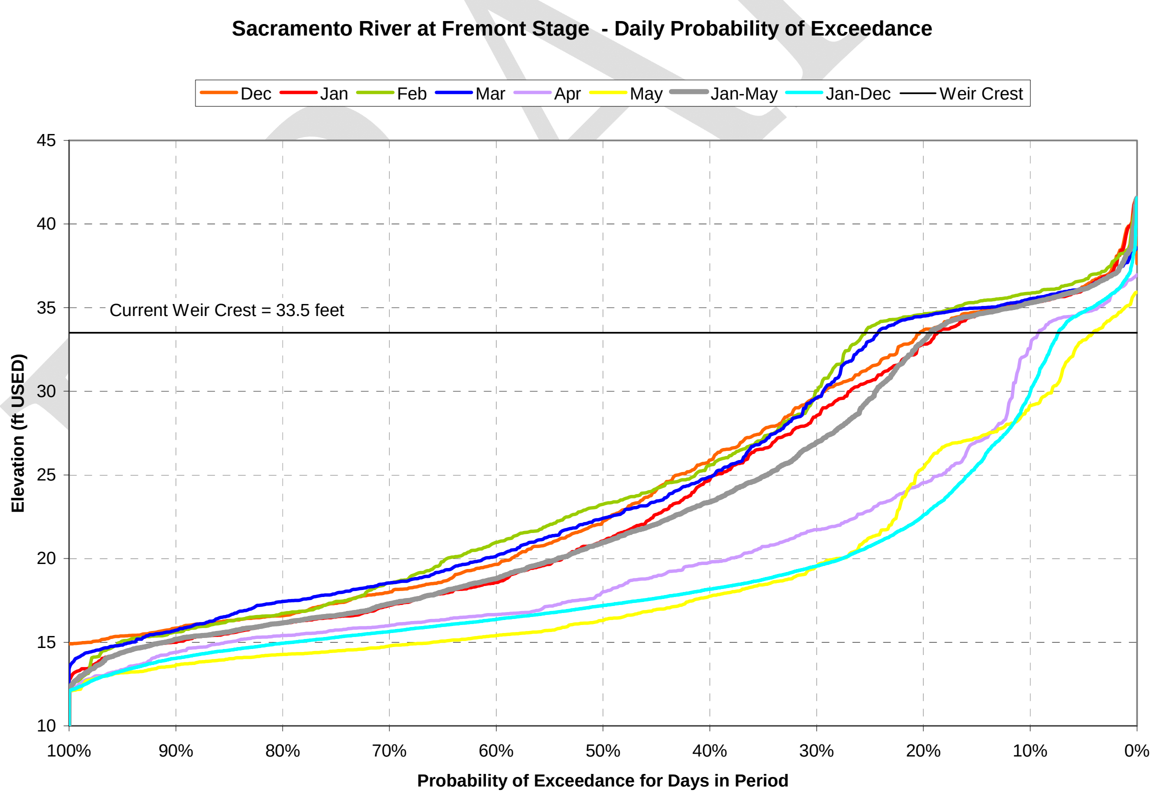

Figure 7: Sacramento River at Fremont stage probability exceedance plot, daily average (1984- 2007).

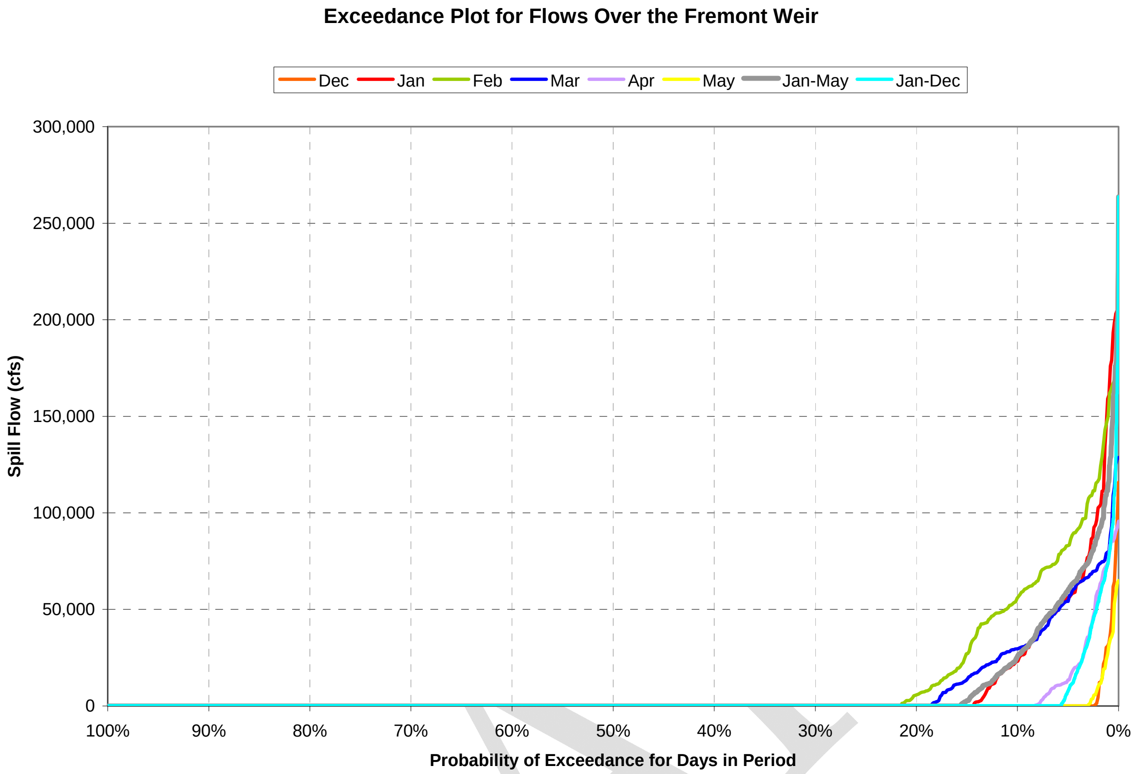

Figure 8: Fremont Weir spills probability of exceedance plot, daily average (1984-2007).

The information provided by the figures above was used to examine the frequency and magnitude of Fremont Weir spills to the Yolo Bypass. Also, the Sacramento River stage exceedance plot (Figure 7) was used to guide the selection of the bottom elevation for the proposed notch.

Relationship between Sacramento River Flow and Fremont Weir Spills

The two sets of estimated daily averages, Sacramento River at Fremont and Fremont Weir spills, were used to develop a relationship to between Fremont Weir spill flow and Sacramento River flow. The equation was found by a polynomial regression on a filtered daily spill data set. The filtered records reflect years where the same trend was followed for a given range of river flow values. In Figure 9, the observed Fremont Weir spill data during the period 1984 to 2007 is shown as a function of the Sacramento River flows. As can be observed, for a river flow range of 50,000 to 90,000 cfs, observed records followed the same trend except from records from years: 1984, 1986, 1993, 1999 and 2006. Even though, years 1995 and 1996 follow a different trend, records from these years were considered in the polynomial regression since the divergence takes place outside the mentioned range.

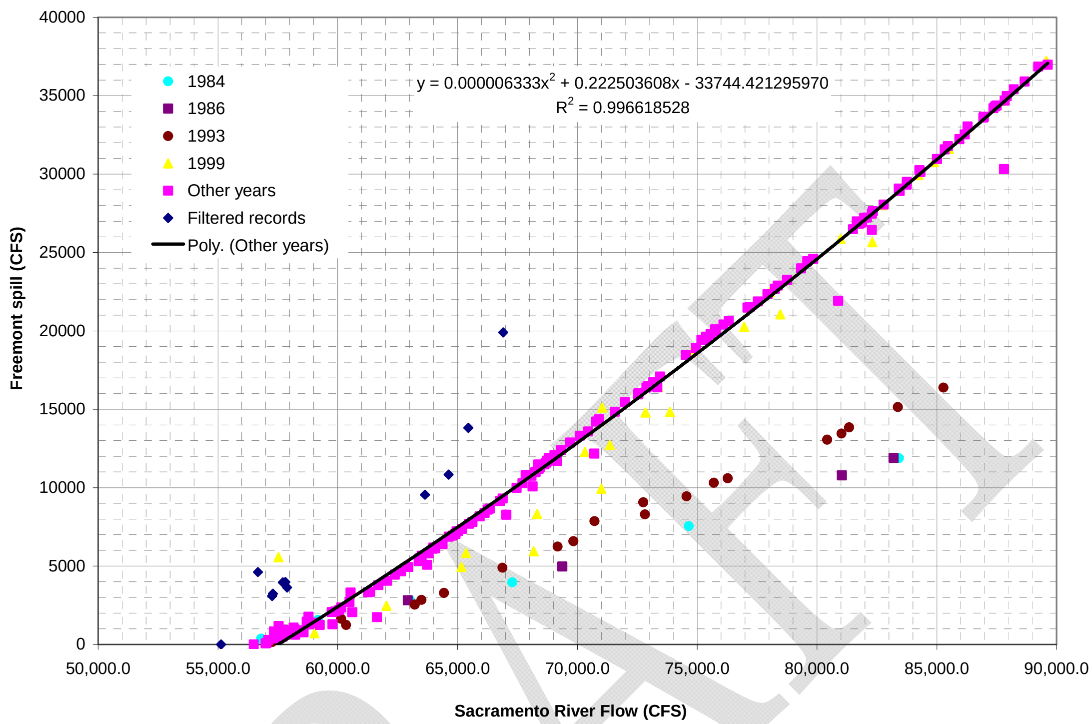

Figure 9: Fremont Weir spills curve for Sacramento flows from 50,000 to 90,000 cfs

Since the Sacramento River at Fremont gage only contains records from 1984 to present, it was desirable to extend the flow time series using the Sacramento River at Verona gage. The relationship between flows at these two locations for the overlapping period is shown in Figure 10. This figure indicates a strong correlation between these flows. Therefore, the equation provided on **Error! Reference source not found.**0 was developed for use in approximating Sacramento River at Fremont flows. The result of this conversion is an extended Sacramento River flow at Fremont time series that was used to evaluate the historical performance of the proposed notch in comparison with the current Fremont Weir configuration.

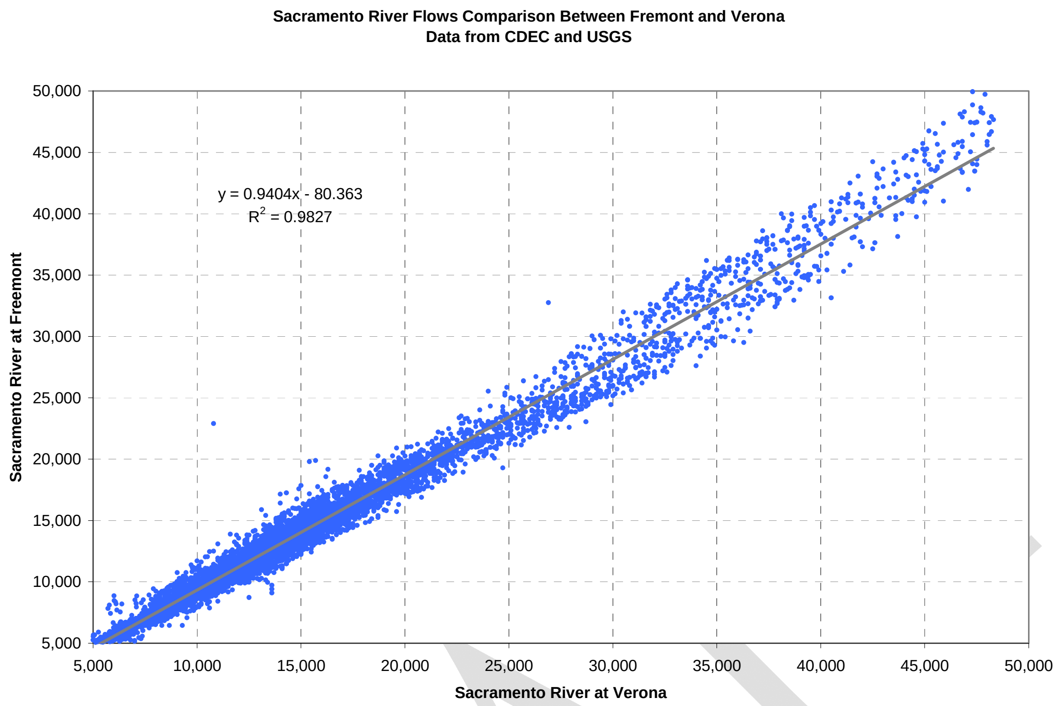

Figure 10: Correlation between Sacramento River at Verona and Sacramento River at Fremont for flows below 50,000 cfs

Using the regression equation described above, the historical Fremont Weir spills into the Yolo Bypass were reconstructed based on Sacramento River flow. **Error! Reference source not found.** shows the correlation between the observed and simulated values for the Sacramento River flow range of 50,000 to 90,000 cfs. The R^2 of 0.9171 and the graph indicate that the regression provides a reasonable estimate of spills over the Fremont Weir. The value is not closer to 1.0 due to the outlier data values from 1984, 1986, 1993, and 1999.

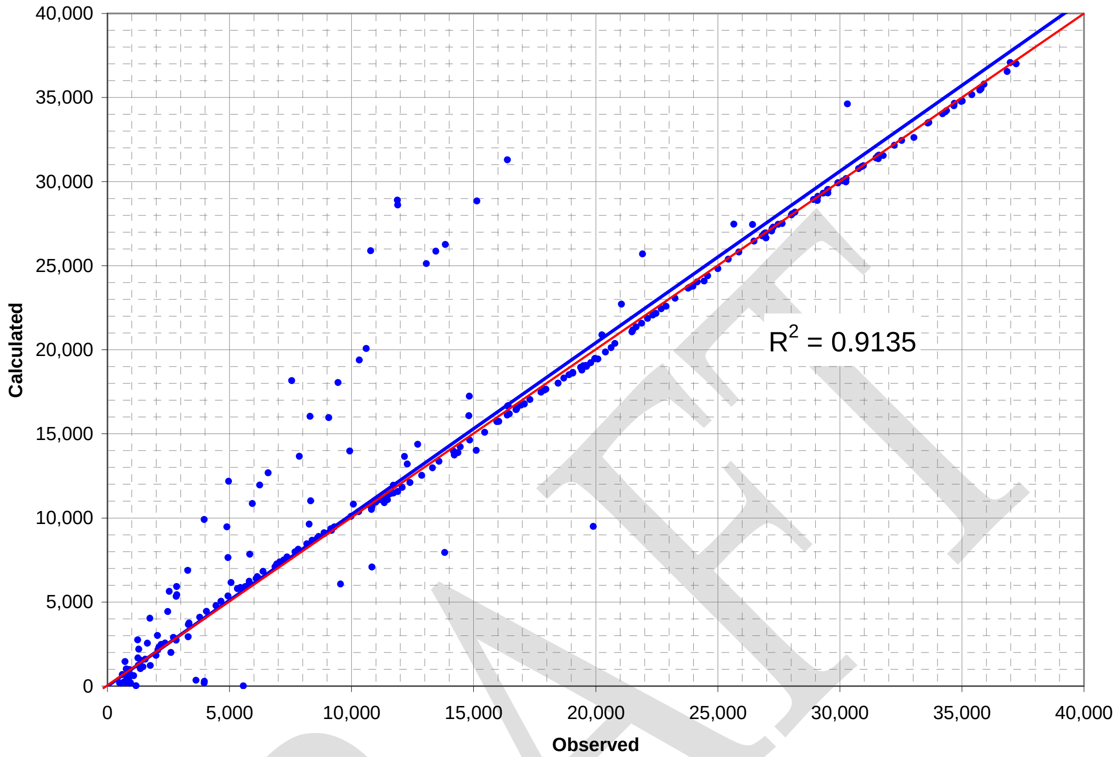

Figure 9: Observed and calculated Fremont weir spill correlation

Assessment of Inundation Characteristics in the Yolo Bypass

Hydraulic Model Development and Application

The inundation characteristics of Yolo Bypass were evaluated by applying a coarse-level HEC-RAS model of the Yolo Bypass from Fremont Weir to Liberty Island. The model was constructed to evaluate approximate inundated area, water depth, and velocities through the Yolo Bypass at various flow levels. The model should be considered preliminary due to limited extent of Toe Drain bathymetry and limited calibration data sets.

Elevation and Bathymetric Data

The initial HEC-RAS model incorporated cross-sections derived from the USGS National Elevation Dataset (NED) Digital Elevation Model (DEM). The NED DEM represents land and water surface elevation, but does not include bathymetric data. In order to better understand the terrain and spatial influence of smaller flows in the Yolo Bypass, a new elevation dataset based on the U.S Army Corps of Engineers (USACE) Yolo Bypass RMA2 Model (USACE, 2007) was subsequently incorporated. The dataset was modified to incorporate surveyed cross section information provided by DWR for 14 cross sections (12 locations) between Liberty Island and I-80. The location of the survey points are shown in Figure 12. The elevation dataset from the USACE Yolo Bypass Model only contained bathymetry data for the region near Liberty Island; other areas reflected either land or water surface elevation.

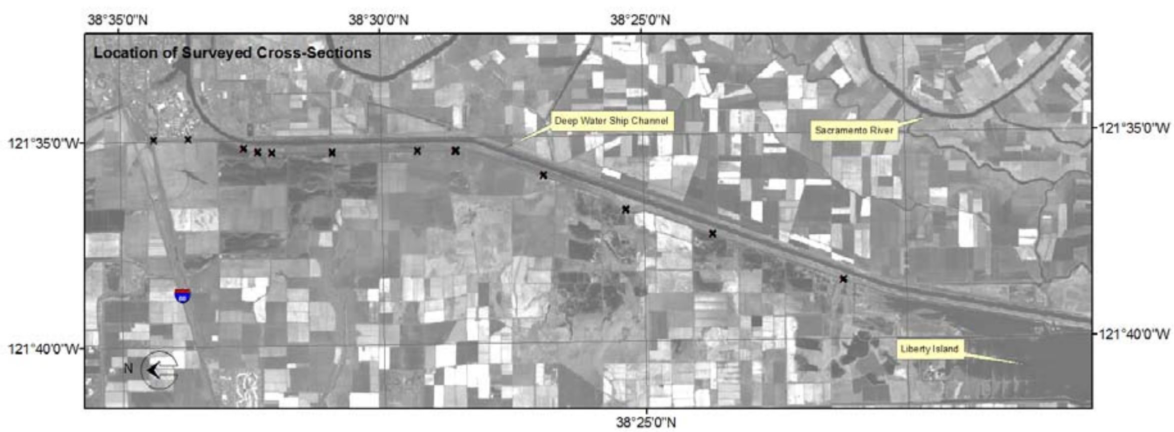

Figure 10: Location of surveyed Yolo bypass East Toe Drain cross sections (DWR unpublished data)

After converting to proper coordinates and vertical datum, a Triangulated Irregular Network (TIN) elevation surface was created with the merge of the USACE model elevation data and DWR survey points. The TIN was then used to generate cross sections of the Yolo Bypass for use in the HEC-RAS model. No cross section data was available for the Toe Drain canal from the Sacramento Weir to near the Fremont Weir. The cross-section of the region was estimated based on the available cross sections for the Toe Drain obtained from the DWR survey.

Boundary Conditions and Hydraulic Parameters

A HEC-RAS steady flow analysis was performed at 100, 250, 500, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, 8,000, 9,000 and 10,000 cfs. The steady flow conditions assumed a downstream water surface elevation of 1.25m (4.1 ft NAVD 1988), which corresponds to observed average stage data from Yolo Bypass at Liberty Island location (CDEC station LIY). The LIY CDEC station is under tidal influence and could range from 0 to 2.5m.

One single manning coefficient value was assumed for all cross sections along the length of the bypass. The USACE Yolo bypass 2-D model (USACE, 2007) assumes that 70% of the land is covered by agricultural fields and had Manning's coefficient as 0.03. The remaining 30% of land has a significant percentage that is assumed to be covered by wild grassland, with a manning's coefficient of 0.045. This current modeling effort assumes that a Manning's value of 0.04 was appropriate to cover the entire Yolo Bypass given the calibration limitations and goals of the model.

Model Results

A profile of the entire Yolo Bypass with the water surface elevation for 1,000, 5,000 and 10,000 cfs is presented by **Error! Reference source not found.**. The units for elevation and cross section distances are in meters due to the HEC-HAS output data. The profile shows the lowest point of each cross section, from the Fremont Weir to Liberty Island, which represents the Toe Drain or Tule Canal profile. The profile also indicates the approximate location of the surveyed cross sections. Flows greater than 1,000 cfs are expected to begin causing inundation outside of the Toe Drain. Table 2 presents the simulated mean depth, surface area, mean velocity, and travel time for various Fremont Weir flows. The high depth and low surface area for 1,000 cfs flow is due to the fact that most of the flow stays within the Toe Drain.

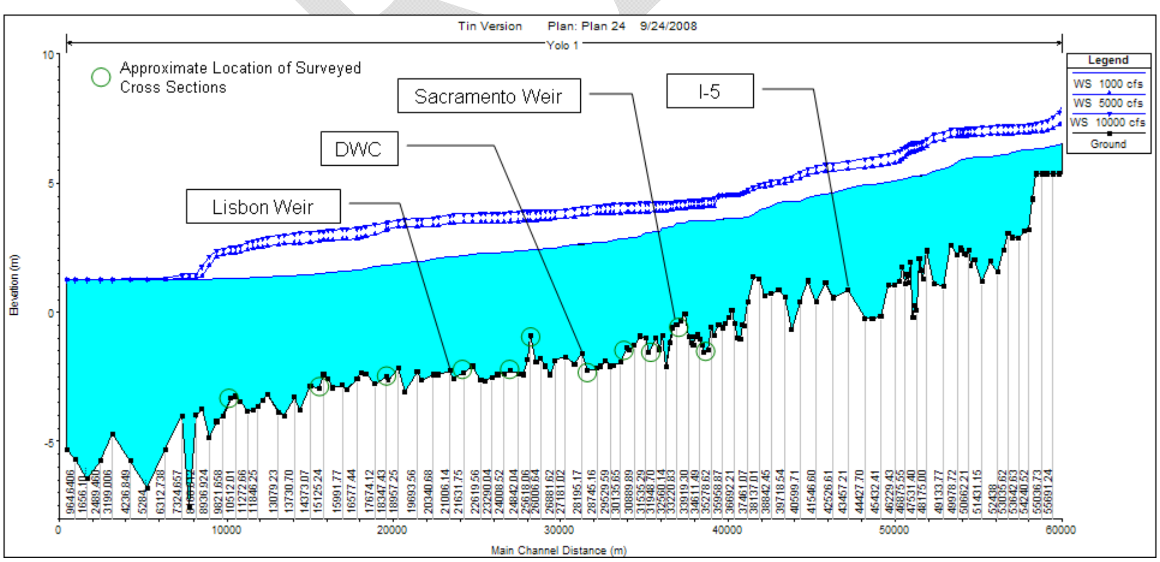

Figure 113: Yolo bypass profile for the deepest point of each cross section. Values in metric units from HEC-RAS analysis

Table 2: HEC-RAS model results for depth, area mean velocity and travel time for different flows at the modified Fremont weir

Flow	Mean Depth for the Entire Yolo Bypass	Surface Area (from GIS mapping)	Mean Velocity	Travel Time
(Q) cfs	(D) ft	(A) Acres	(V) ft/s	(t) day
1,000	5.1	5,733	0.94	9.9
2,000	2.3	17,421	0.58	9.3
3,000	2.2	20,579	0.60	7.5
4,000	2.2	22,982	0.61	6.5
5,000	2.4	25,077	0.63	5.9
6,000	2.5	26,355	0.68	5.3
7,000	2.6	27,450	0.72	4.9
8,000	2.7	28,515	0.77	4.6
9,000	2.8	29,634	0.79	4.4
10,000	2.9	30,595	0.81	4.2

The surface area field in Table 2 represents more detailed area values then what is obtained directly from HEC-RAS results, which interpolates areas between cross sections. The areas in Table 4 were obtained by transferring the HEC-RAS model results to GIS and computing areas. **Error! Reference source not found.** shows the inundated areas for various flow levels determined from the GIS mapping. Due to the topography of the Yolo Bypass, there is a dramatic increase in surface area as flow exceeds that which can be conveyed in the Toe Drain. At 5,000 cfs flow, approximately 25,000 acres are expected to be inundated, but this value is only increased to 30,000 acres at 10,000 cfs. It should be noted that the surface area values in Table 2 include approximately 3,700 acres of Liberty Island that were constantly inundated. This amount should be subtracted of the total flooded area presented in Table 2 to estimate total new flooded areas. For comparative analysis this is not significant since the Liberty Island flooded area remains practically unchanged through the range of flows considered in this report.

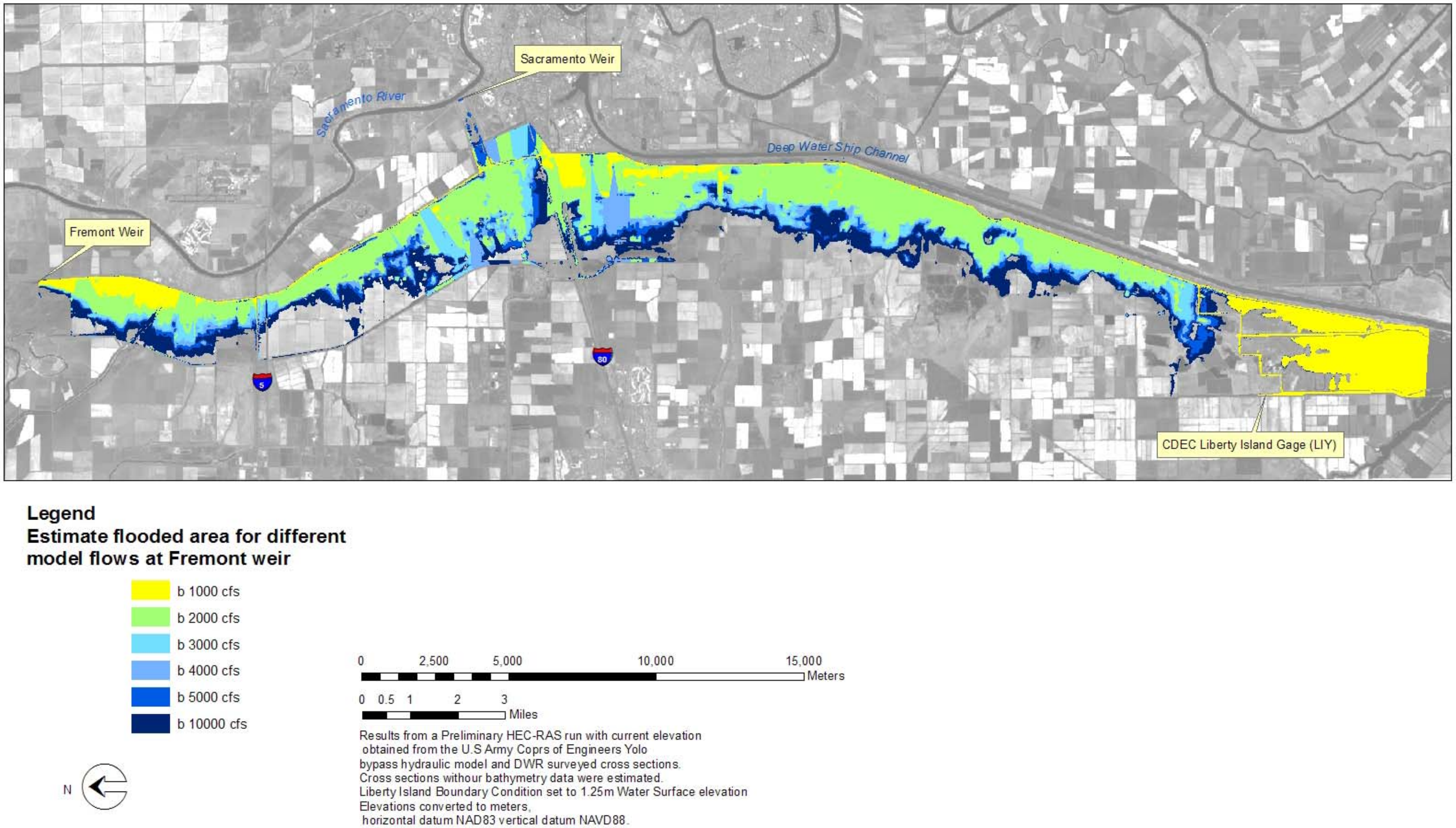

Figure 14: HEC-RAS modeling results showing flooded areas at different Fremont weir notch flows

Model Comparison

The results presented on previous sections were compared with results of a linear interpolation model published by Sommer et al. (2004). In Sommer et al., linear interpolation of gage elevations between stations was used to estimate water surface between gages. **Error! Reference source not found.**15 presents a comparison between the final HEC-RAS model and the model results published by Sommer et al. (2004). The comparison shows that the linear interpolation model compares reasonably well at low flows but overestimates areas for high flows when compared with the hydraulic HEC-RAS model. A possible explanation for the difference between the linear interpolation and the HEC-RAS model results may be due to the assumption used in the Sommer et al that the water surface elevation has a constant slope, which may not be valid at higher flows. This assumption may overestimate areas if gages are spaced apart by long distances, which is the case of the two gages used in the interpolation model that are covering the area between I-5 and Lisbon weir. **Error! Reference source not found.** illustrates how possible overestimation could occur in high flows between two gages used in the linear interpolation model. It is also important to note that the HEC-RAS simulations only consider flows over the Fremont Weir and do not account for tributary flows. Although there is a significant difference between the HEC-RAS and the linear interpolation models at higher flows, both models show that the increase in inundated areas is reduced at flows greater than 5,000 cfs.

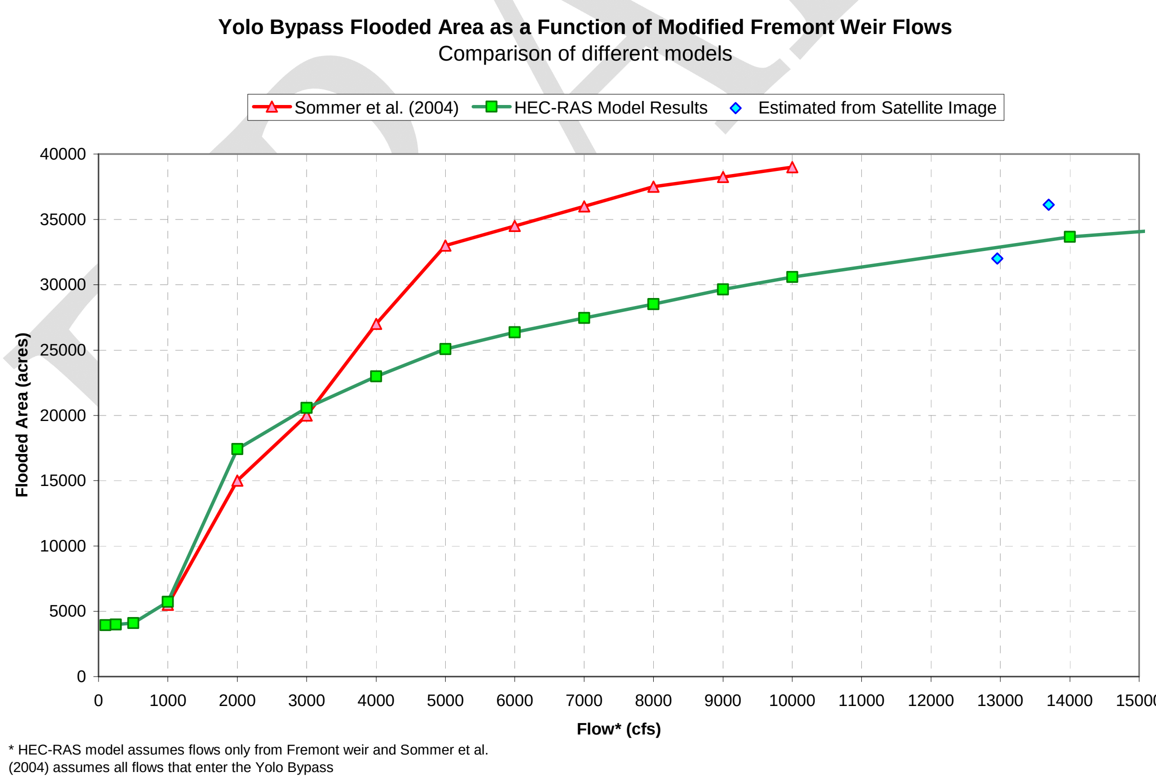

Figure 15: Comparison of flooded area for different models and models assumptions.

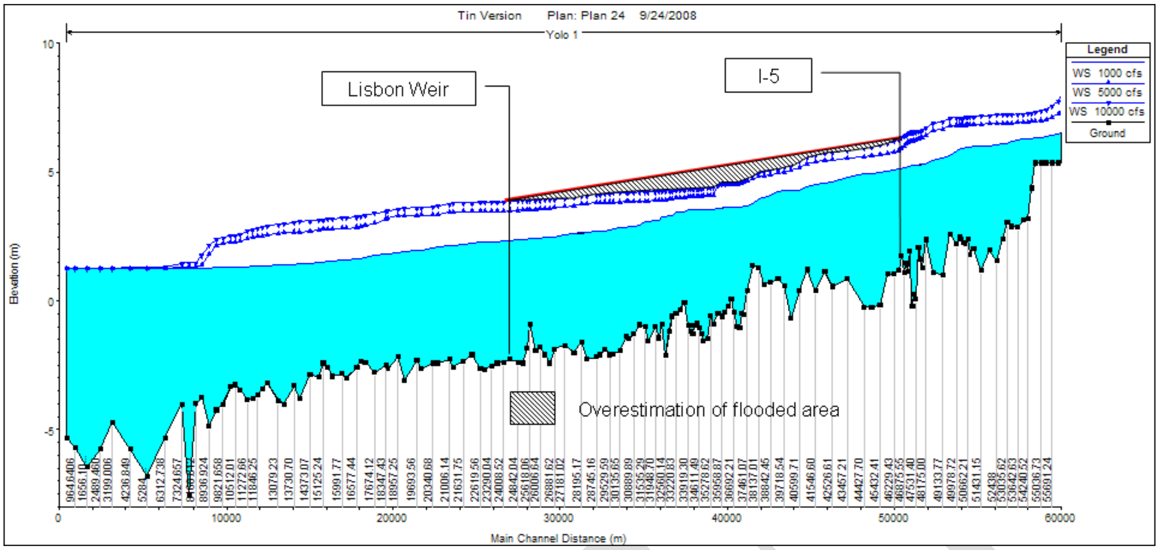

Figure 16: Possible overestimation of flooded areas using a linearization of water surface between two stations

A comparison of HEC-RAS modeling results against flooded areas registered by satellite images was also performed. Four spill events with were found among several satellite images. **Error! Reference source not found.**3 lists the 4 events, the estimated flows at Fremont Weir as an average for the last 7 days, and the estimated area delineated from a 300X300m resolution images. The HEC-RAS simulated area results compare well to those estimated from the images. The January 2003 and February 2006 events are included in Figure 15.

Table 3: Estimated flooded area from satellite images and the respective previous 7 day average of Fremont flows. Values rounded to the thousands.

Date	Flow – HEC-RAS[1] (cfs)	Area – satellite image[2] (acres)	Area – HEC-RAS (acres)
March 6, 1998	48,000	51,000	51,000
January 15, 2003	13,000	32,000	35,000
February 8, 2006	14,000	36,000	36,000
April 13, 2006	72,000	48,000	56,000

[1] Estimated flow based on Fremont Gage for the previous five days. May underestimate since tributary flow is not included.
[2] Estimated acreage based on rough delineation from 300mx300m satellite image.

Potential Modification of Fremont Weir

Range of Target Flows in the Yolo Bypass

The range of target flows in the Yolo Bypass was evaluated based on anticipated inundated area, water depth, and travel times. Based on the modeling results and comparison to previous work, it was believed that flows in the range of 2,000 to 6,000 cfs would provide sufficient surface area and water depths for desirable habitat. For these flows, the mean water depths were generally within the 2-3 foot range, velocities were less than 1.0 feet per second, and travel times were in the range of 4-8 days. The anticipated inundated area would range between 20,000 and 26,000 acres.

Proposed Modification to the Fremont Weir - Hydraulic Model Assumptions

To simulate a proposed notch in the Fremont Weir, the HEC-RAS hydraulic model was modified to include 12 new cross sections near the Fremont Weir representing the notch. The modified Fremont Weir would need to be able to convey, by gravity, the desirable flows into the Yolo Bypass. The initial assumption was to consider a new channel with invert at 17.53 ft NAVD 88 (18 ft USED). The 17.53 ft elevation was chosen as a function of two criteria, the terrain elevation between Fremont weir and Tule Canal, and the Sacramento River flow at Fremont.

As a reference for the first criterion, **Error! Reference source not found.**7 shows the surface profile for the cross section that represents the alignment of the new structure going from Sacramento River (zero distance) to the beginning of the Tule Canal (approximately 10,000 ft) (see Figure 1). **Error! Reference source not found.**7 also shows the estimated invert of Tule Canal (11.6 ft NAVD 88) and the new channel bottom elevation (17.5 ft NAVD 88). To avoid major earth work and potential backwater effects, the bottom of the new structure was kept above the Tule Canal invert elevation.

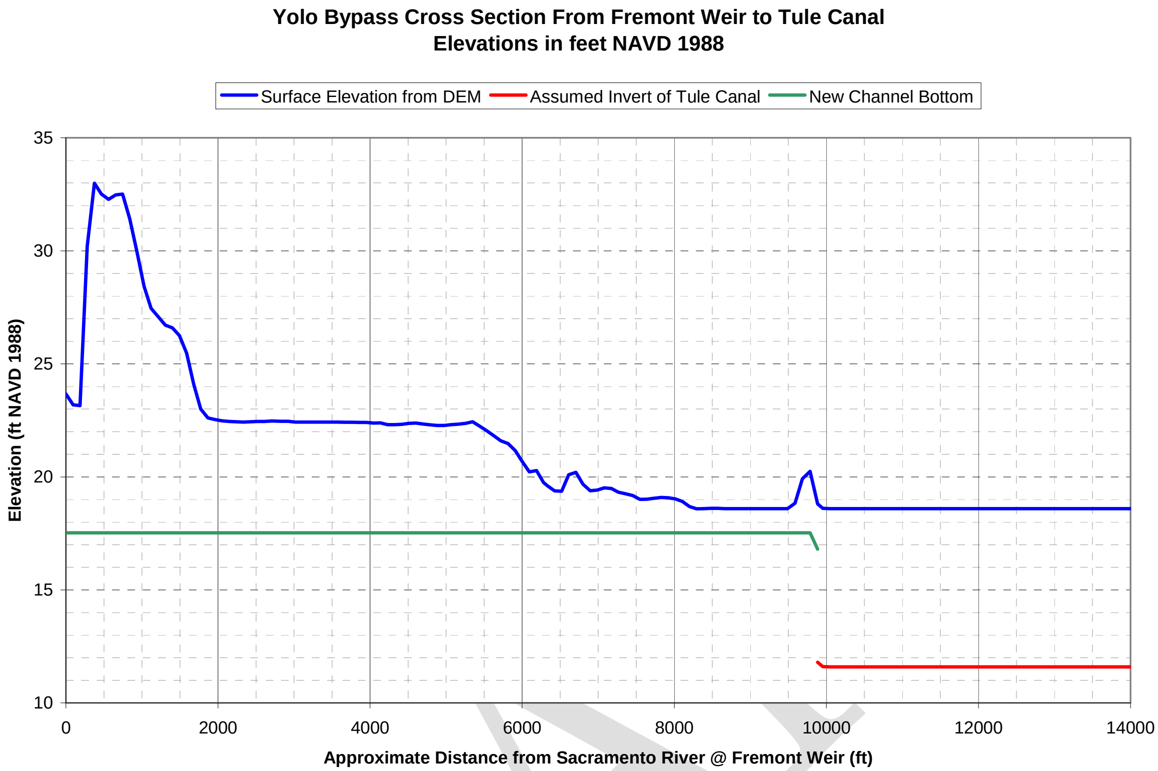

Figure 127: Yolo Bypass Profile from Sacramento River at Fremont Weir to Tule Canal

A second criterion was used to evaluate whether the notch and canal would be sufficient to convey the target flows into the Yolo Bypass with a reasonable frequency. Historical Sacramento River flows at Verona were used to estimate a range of flows that may occur in the future. According to **Error! Reference source not found.**8, daily flows exceeding the range of 20,000 to 40,000 cfs would occur around 50% of the days within the January to March time period. This flow range was used in the initial elevation setting of the proposed notch. This flow range at Verona roughly correlates to 18,000 to 28,000 cfs at Fremont and roughly 19.5 to 24.5 ft NAVD88 at Fremont Weir.

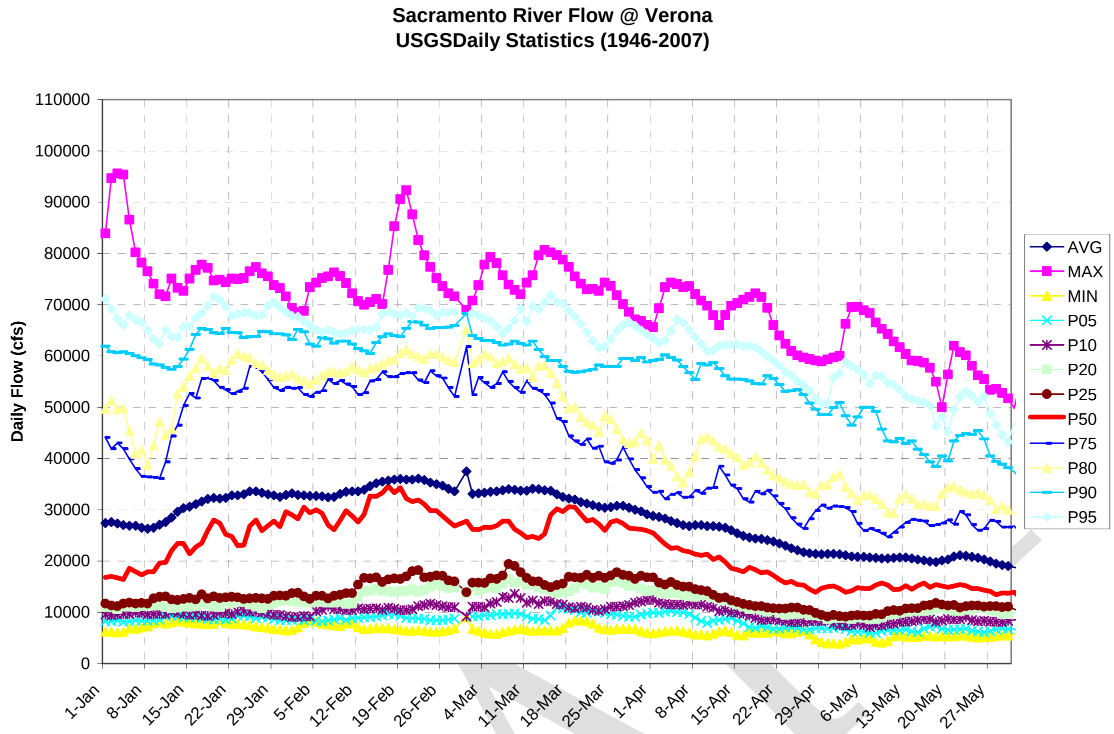

Figure 138: Daily statistics data from USGS for Sacramento River at Verona

Once the elevation and flow conditions at Fremont were better understood, the cross section dimensions for the notch were approximated. **Error! Reference source not found.** presents the dimensions for the trapezoidal channel structure connecting the Fremont weir to the Tule Canal. The figure shows the channel with bottom length of 225 ft, side slopes of 2:1 and top length of 287 ft. The channel dimensions were estimated to avoid channel velocities greater than 3 ft/s. It was assumed that the new structure would operate most of the time conveying flows below 10,000 cfs.

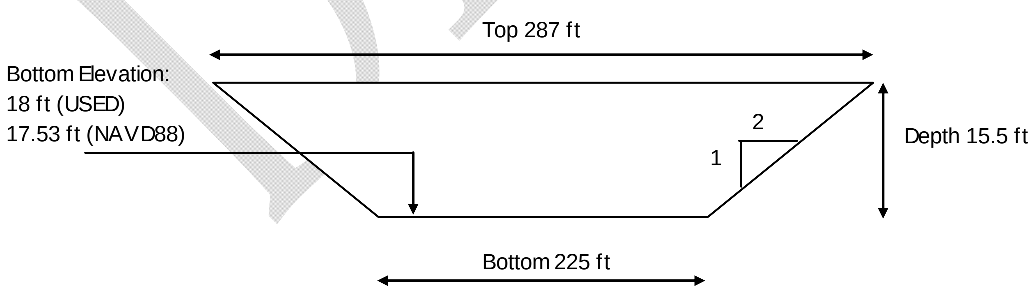

Figure 149: Dimensions for the channel connecting the Fremont weir to the Tule Canal at the Yolo Bypass

Potential Fremont Weir Notch Rating Curve

A rating curve for the modified Fremont Weir was developed from the HEC-RAS results and shown in **Error! Reference source not found.** and **Error! Reference source not found.**4. These results will be used in CalLite and CALSIM models using Sacramento Flow at Verona as a trigger for the Fremont Weir modification. The curves presented by **Error! Reference source not found.**, show that the defined range of Verona flows (30,000 cfs-50,000cfs), that represents approximately the area between the 50th and the 70th percentile of flows during February and March, will result in a 0 cfs to 7,000 cfs range of flows flowing into the Yolo Bypass.

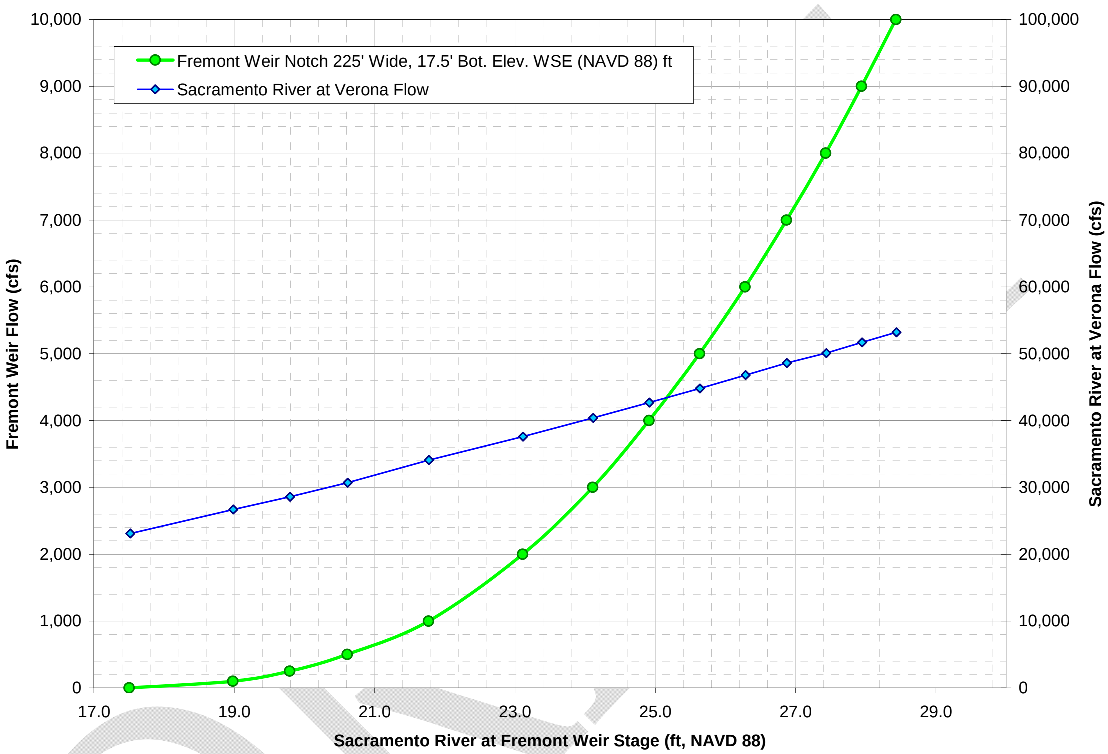

Figure 20: Rating curves for the modified Fremont weir and Sacramento River flow at Verona

Table 4: Summary table for the new structure diversion to be used with CalLite and CALSIM models

Sacramento River at Fremont Stage ft (NAVD 88)	Notch Flow: Unrestricted (cfs)	Notch Flow: Proposed Limits (cfs)	Sacramento River at Fremont Flow (cfs)	Sacramento River at Verona Flow (cfs)
17.5	0	0	14600	23100
19.0	100	100	17500	26700
19.8	250	250	18600	28600
20.6	500	500	20000	30700
21.8	1000	1000	22200	34100
23.1	2000	2000	24800	37600
24.1	3000	3000	26800	40400
24.9	4000	4000	28900	42700
25.6	5000	4000	30700	44800
26.3	6000	4000	32600	46800

26.9	7000	4000	34400	48600
27.4	8000	4000	35700	50100
27.9	9000	4000	37300	51700
28.4	10000	4000	38700	53200

Model Sensitivity

Since the actual design of the modified Fremont Weir is unknown and is beyond the scope of this study, an analysis was conducted to evaluate whether the frequency and magnitude of flows could be increased by enlarging the channel bottom width from 225 ft to 450 ft. Initially, it was expected that the ability to convey flow on a wider channel would increase significantly. The expected increase in channel capacity is presented in **Error! Reference source not found.**, where T 225 ft and T 450 ft are theoretical channels with constant bottom slope, constant dimensions, same manning coefficient, and flowing at normal depth. Through greater examination of the model cross-sections, we identified an area approximately 32,000 ft downstream from the Fremont Weir into the Yolo bypass that serves as a hydraulic constriction, especially at low flows. This terrain elevation condition limits the effectiveness of a wider channel capacity to provide more flow. An improved high-resolution elevation data set would assist in identifying whether this area truly acts in this fashion. This kind of investigation, however, is beyond the scope of this study.

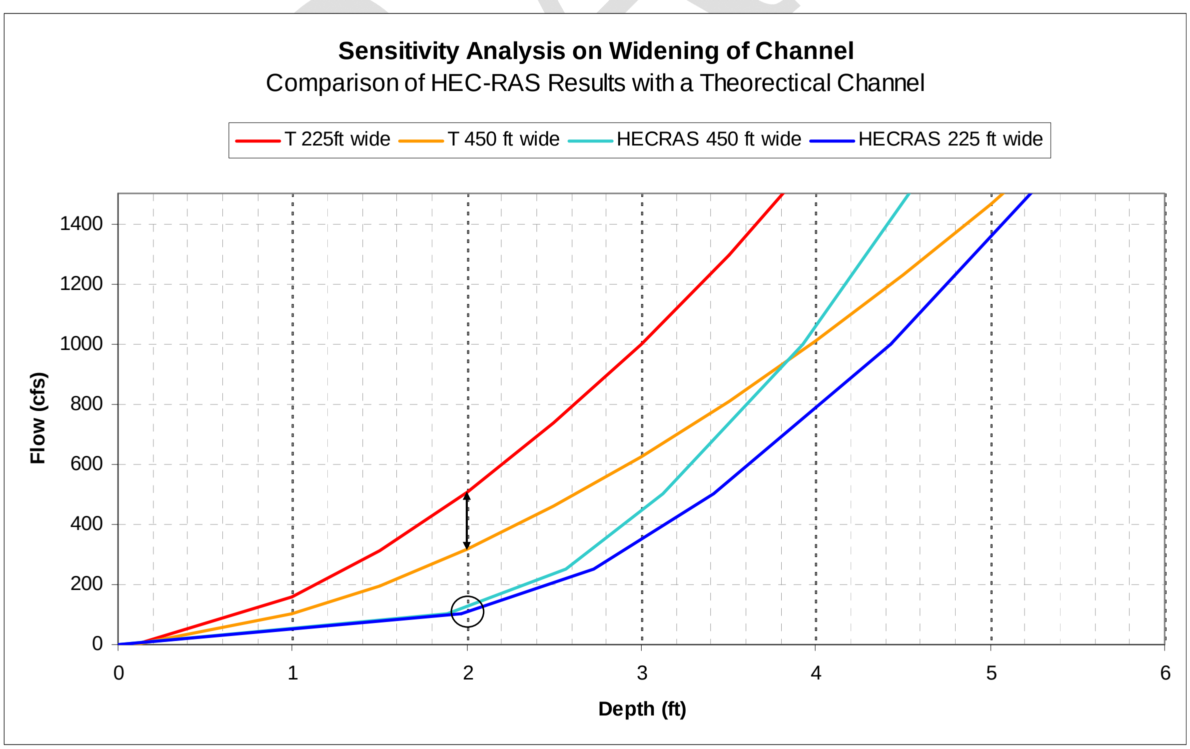

Figure 15: Sensitivity analysis on the effects of widening the spill channel

Comparison between Current and Proposed Fremont Weir Configurations

The two scenarios, current and proposed Fremont Weir configurations, were analyzed over a nearly 80-year (October 1929 – July 2008) reconstructed daily flow sequence using the hydrologic data sets, spill flow equations, and the rating curves described in previous sections. The probability of occurrence of spills over the Fremont Weir significantly increases with the proposed notch. **Error! Reference source not found.** and **Error! Reference source not found.** show the exceedance plots for current and modified Fremont Weir, respectively. With the modified Fremont Weir it is expected that daily flows during the Jan-May period will exceed 2,000 cfs approximately 45% of the time in contrast to only 8% of the time with the current configation. The months of January, February, and March will have significantly higher chances of sufficient daily flows as compared with April and May. This analysis assumed a maximum of 10,000 cfs could be passed through the modified weir.

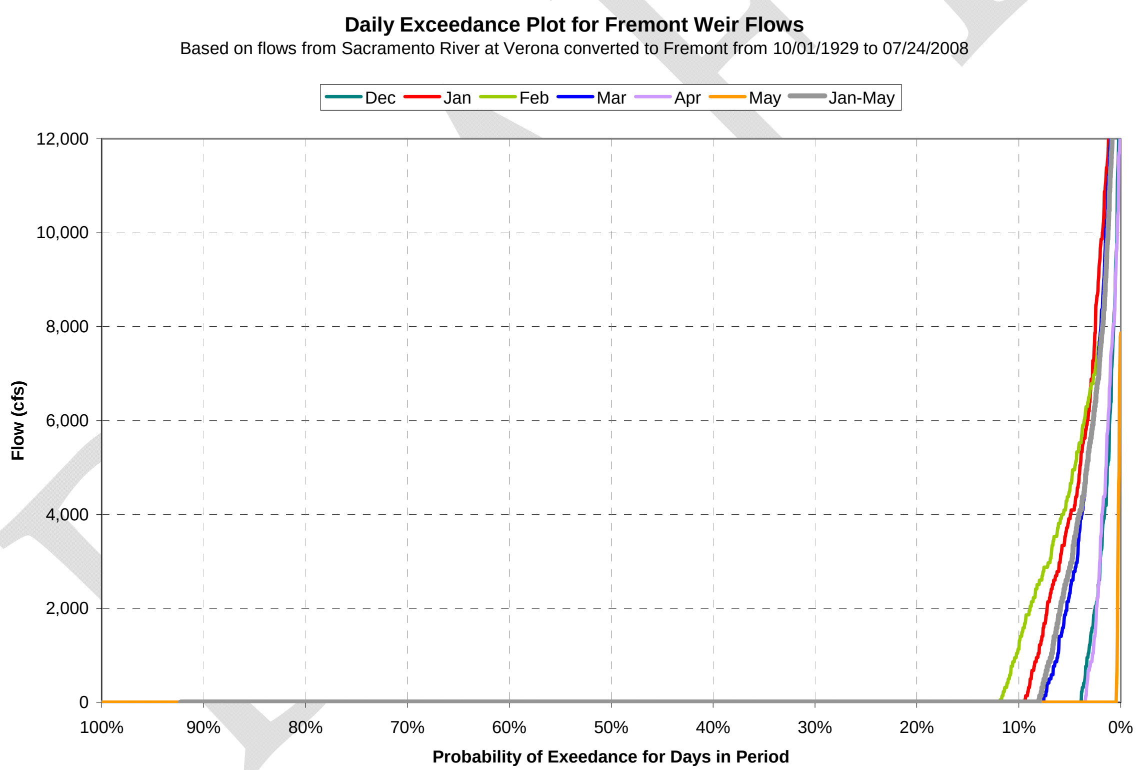

Figure 16: Exceedance plot for current Fremont weir flows for selected months

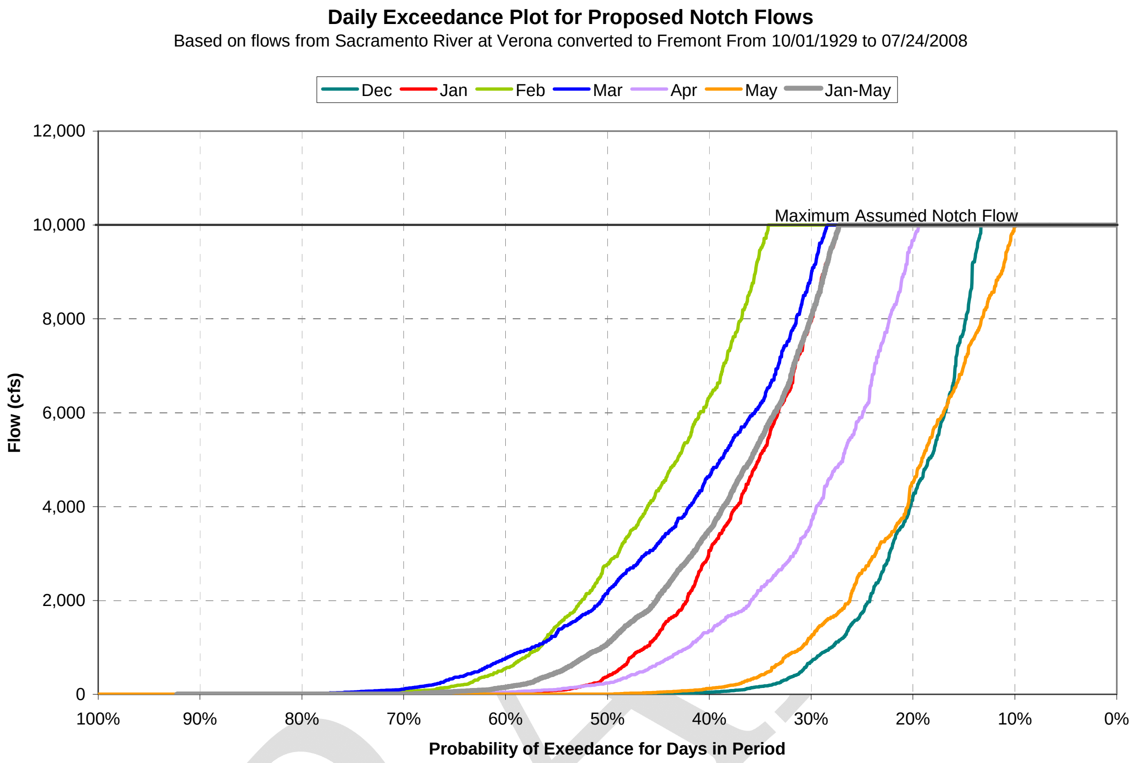

Figure 17: Exceedance plot for modified Fremont weir for selected months

Figures 24 through 26 show the events producing discharges greater than 2000 cfs for the existing and proposed Fremont Weir. The periods greater than 30 days are indicated in the call-outs. The time series line represents stage at Sacramento River at Fremont. The bars represent when a continuous flow (up to a week no flow gap) of more than 2,000 was simulated to spill into the Yolo bypass. The graphs show clearly that January through March is a critical period for spills into the bypass. The maximum number of days that continuous flows greater than 2,000 cfs were observed was 174 days in 1998. A more realistic operation of the proposed modified Weir structure (notch and gate) would only permit flows during the January 1 through April 15 period and limit notch flows to the 2,000 - 4,000 cfs range. This operation is shown in Figures 24 through 26 as green bars.

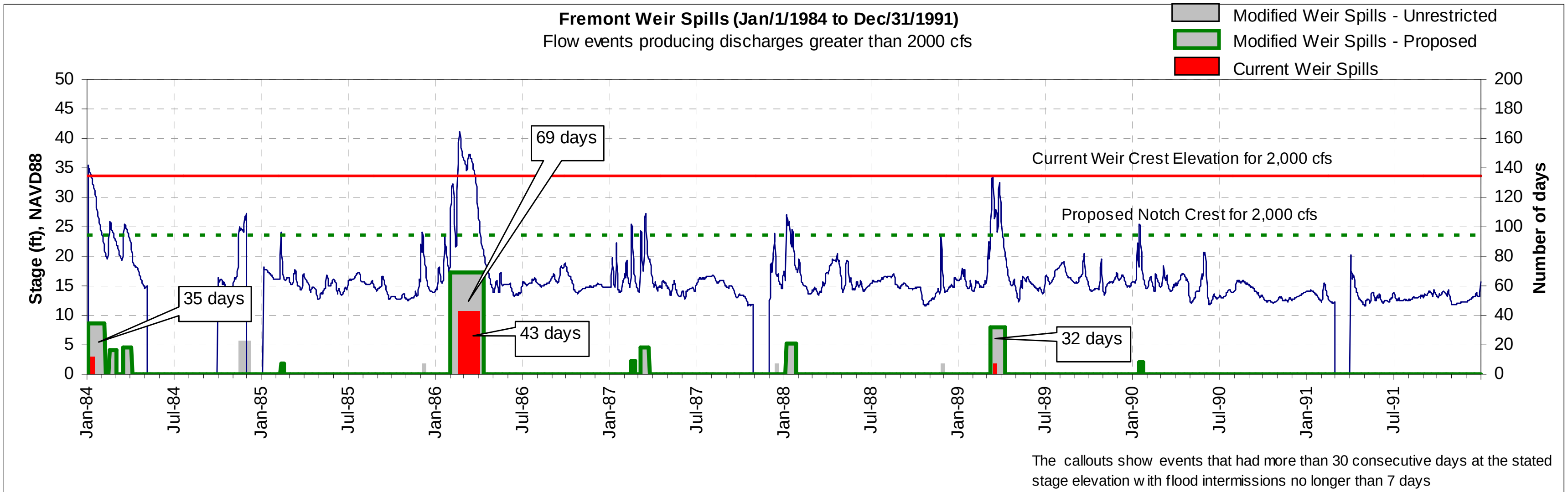

Figure 18: Events producing discharges greater than 2000 cfs for more than 30 days (1984-1991)

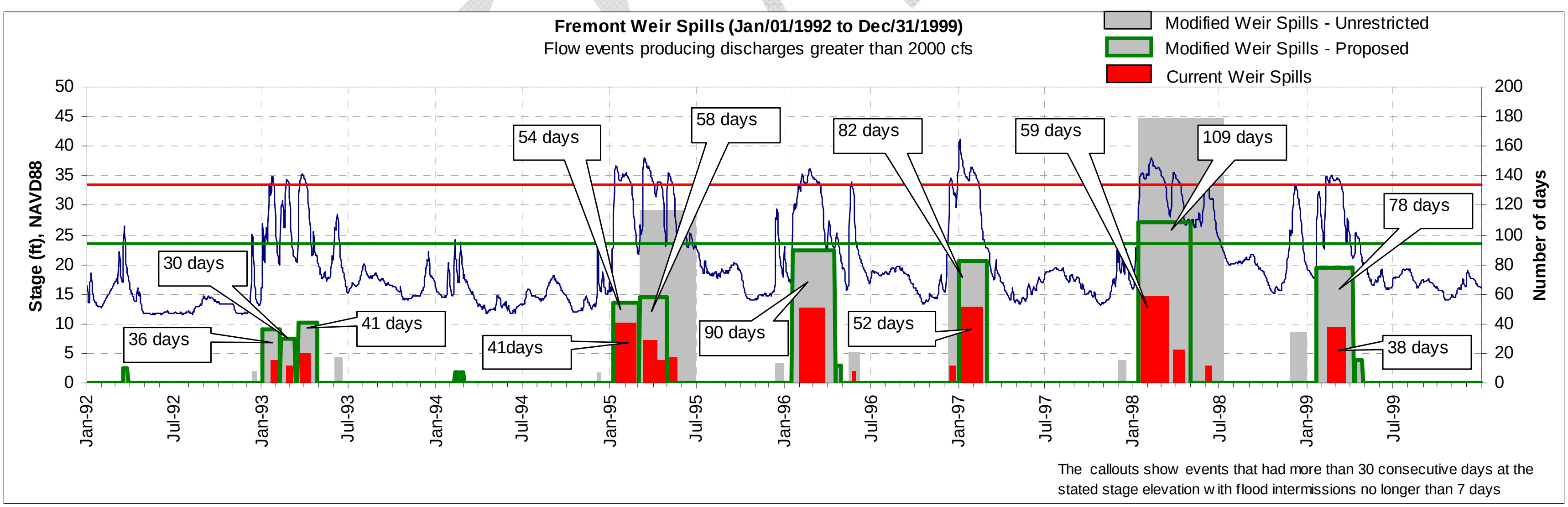

Figure 19: Events producing discharges greater than 2000 cfs for more than 30 days (1992-1999)

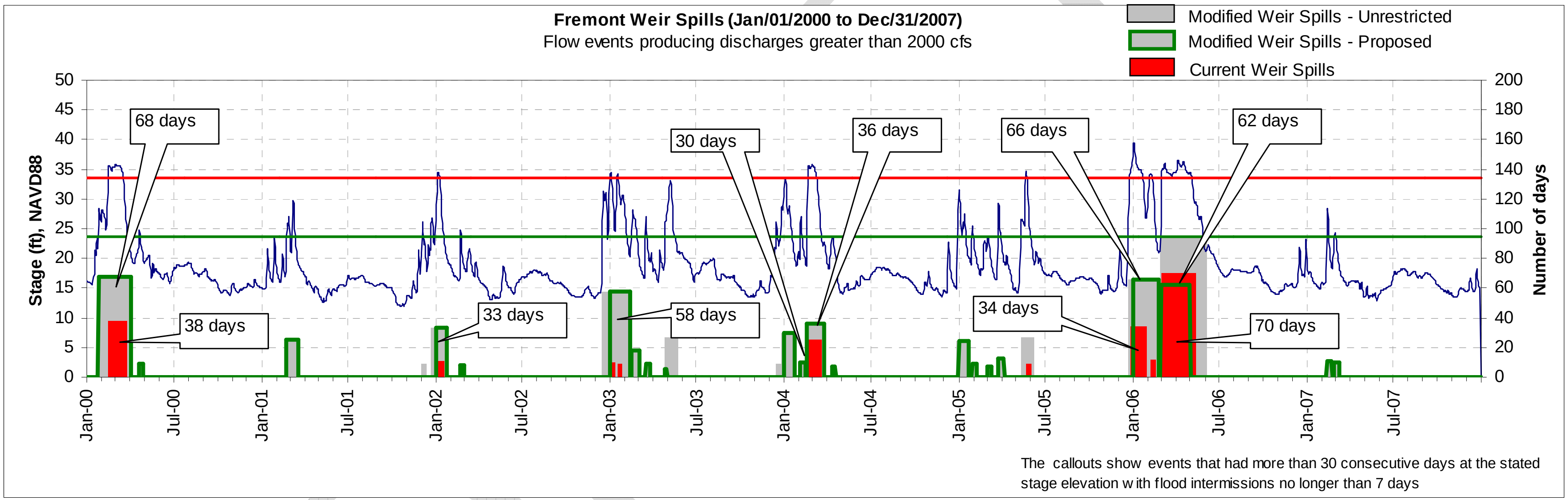

Figure 20: Events producing discharges greater than 2000 cfs for more than 30 days (2000-2007)

Table 5 presents a summary of the change in events that produce flows greater than 2,000 cfs over the Fremont Weir (current conditions and proposed notch). The table presents the results for the period 1984-2007 (observed flow period) and 1929-2007 (longer reconstructed flow period), the proposed notch would more than double the number of events that are deemed biologically significant.

Table 2: Number of events with consecutive spills producing more than 2,000 cfs over Fremont weir under current and proposed notch conditions

Number of events with consecutive days of spills (max 7 day gap to count as new event) that produced more than 2,000 cfs	Count of events between 1984-2007		Count of events between 1929-2007	
	Current Weir	Proposed Notch	Current Weir	Proposed Notch
Less than 30 days	18	39	48	111
Greater than 30 days	9	20	11	65
Greater than 45 days	4	11	5	43

Limitations

The present model is suitable for a coarse-level feasibility analysis of a modified Fremont Weir. The intent of this study is to show the range of Sacramento River flows at which a modified Fremont Weir becomes feasible and the degree and extent of increased inundation. Another major goal of this analysis was to develop an approximate rating curve for the modified Fremont weir that could be used in other water resources models like CalLite and CALSIM. Additional study would be required to gain greater insight and begin to identify design-level conditions.

For the above mentioned goals of this study, it was acceptable to utilize the USACE elevation from the Yolo Bypass model (USACE, 2007). A detailed Yolo bypass hydraulic model would require a refinement on the number of cross sections used by the model. More cross sections would clarify possible problems like the flow on cross section at 32,000 ft downstream of the Fremont Weir (cross section 47428.85), where an apparent berm acts as a hydraulic constriction. A more refined model would also use different manning coefficients as a function of land use or satellite data and would calibrate results with observed data.

Although a 2-D hydraulic model of the Yolo Bypass (USACE, 2007) is available from the USACE, the model was designed for high flows in the range of 343,000 cfs and 500,000 cfs. The model documentation reports that it will not reliably simulate lesser discharges. In addition to this model limitation, the computational requirements of this model and resources necessary to adapt the mesh for this analysis is beyond the scope of this task.

For the design of the modified weir, a more refined analysis on the missing flow and stage data would be desirable, a detailed survey of the area close to the weir would be necessary and more detailed assumptions would have to be defined like maximum depth and width of the channel.

Coarse satellite images were used to estimate flooded areas (300x300 m resolution) and not enough time was spent on defining the correlation between Fremont weir flows, time of travel and floodplain area inundated. However, in the future this technique could be refined and be used as a calibration tool for the model.

Hydrological Modeling Summary

Despite the coarseness of this study, several broad conclusions can be made. First, the lowering a channel through the Fremont Weir has the potential to significantly increase the frequency of inundation of the Yolo Bypass. The frequency of providing biologically-important flows is doubled as compared to the current configuration. It appears that the increase in frequency is a more robust result than the increase in magnitude of flows. Second, the hydraulics in the upper reach are important. The profile suggests that low flows may be affected by downstream hydraulic controls. Higher resolution elevation mapping, cross-sections, and more detailed modeling would be important to better understand these conditions. Finally, the modeling has shown that sufficient velocities, depths, and general residence times could be achieved from flows >2,000-3,000 cfs. The modeling has assumed that the Yolo Bypass would not be altered. It is likely that land use and other concerns will require that certain lands be inundated, while adjacent lands are not. When these decisions are made, it will be important to verify the hydraulic conditions to ensure that conditions both upstream and downstream are suitable for the habitats of concern.

Existing Knowledge of the Biological Effects of Floodplain Inundation in the Yolo Bypass

Current research indicates that there are both positive and negative biological effects of floodplain inundation in the Yolo Bypass. Here we provide a general overview of these effects. A complete list of anticipated effects of Yolo Bypass floodplain inundation for all covered fish species is located in Table ##.

Positive Biological Effects

Spawning and Rearing Habitat

Results of studies within the Yolo Bypass have shown the presence of both adult fish and larval/juvenile lifestages suggesting successful spawning and rearing within the inundated habitat (Harrell and Sommer 2003, Sommer et al. 2004b). Species that appear to have successfully spawned in the inundated bypass include Sacramento splittail, American shad, striped bass, threadfin shad, largemouth bass, and carp. Other species such as bluegill, channel catfish, black crappie, and Sacramento sucker may also spawn within the bypass. Several of these species such as striped bass may spawn primarily in the toe drain. Other species such as splittail migrate upstream and spawn in seasonally inundated floodplain margin habitat (associated with flooded vegetation). Seasonal inundation of floodplain habitat within the Yolo Bypass has been identified as a significant spawning habitat for splittail. A majority of the Sacramento River channel, as well as Delta channels, have been constrained by levees resulting in the loss of most seasonally inundated floodplain habitat that would be suitable for splittail spawning within the watershed (Feyrer et al. 2005). Splittail larvae were captured within the Yolo Bypass during seasonal inundation in 1999, 2000, and 2002 (Sommer et al. 2004b). Sommer et al. (1997) provide a comparison of indices of juvenile splittail abundance within the Bay-Delta estuary based on the fall midwater trawl surveys that shows an average abundance index of approximately 5 during those years when the Yolo Bypass was flooded fewer than three weeks compared to an abundance index averaging approximately 39 in those years when the Yolo Bypass was flooded for more than three weeks. Typically splittail spawn in March and April, depositing adhesive eggs on submerged vegetation and other substrates. After hatching, the larval and early juvenile splittail forage and rear along the inundated floodplain prior to moving downstream into the estuary as recession occurs. Juvenile Chinook salmon are known to rear in the Yolo Bypass where they encounter high densities of prey which, in combination with other factors, may contribute to higher growth rates compared to the mainstem Sacramento River (see “Growth Rate of Juvenile Chinook Salmon” below).

Productivity

One of the predicted benefits of increasing inundation of the Yolo Bypass is an increase in phytoplankton biomass and other food resources that support juvenile and adult fish inhabiting the floodplain (e.g., rearing juvenile Chinook salmon and splittail), as well as within the lower river and Delta. During periods when the bypass is not flooded, terrestrial vegetation, including naturally colonizing grasses and shrubs as well as irrigated agricultural crops grow within the bypass. During periods of inundation, organic material in the form of uprooted and decaying vegetation, leaves, and associated insects and other organisms and nutrients become available to the aquatic food web. Schemel et al. (1996) observed that the floodplain was the dominant source of organic carbon to the estuary in wet years, which also correlates to the periods when estuarine production and larval fish abundance is greatest within the downstream estuary. Organic material and nutrients within the bypass support the local production of phytoplankton as well as a variety of invertebrates that serve as a food resource for various fish and other organisms. Phytoplankton and organic matter produced within the inundated bypass not only increase the availability of food supplies for fish within the bypass but also are transported downstream into the lower Sacramento River and Delta by flows passing through the bypass (Sommer et al. 2001).

Schemel et al. (2004) investigated the relationship between seasonal inundation characteristics of the Yolo Bypass and phytoplankton production. Results of these investigations showed that phytoplankton production (measured as Chlorophyll a) was low when flows through the bypass were high (associated with high flood flows) but increased significantly as flows through the bypass decreased and the floodplain drained. These investigations also showed that the contribution of local tributaries was important in adding both flow and dissolved organic nutrients to the seasonally inundated floodplain. It was hypothesized that flows that increased the inundated bypass surface area but were slow and shallow were important to phytoplankton production within the bypass. Phytoplankton production was also found to be greater as water temperatures increased and seasonal illumination (day length and sun light) increased in the spring. Lehman et al. (2008) reported similar findings noting that during seasonal inundation of the Yolo Bypass the production of diatoms and green algae increased significantly within the bypass compared to the adjacent Sacramento River and that seasonal inundation of the bypass resulted in an export of phytoplankton and nutrients to the lower Sacramento River. In 1998, studies of chlorophyll a showed that concentrations within the lower Sacramento River closely followed the floodplain inundation hydrograph for the Yolo Bypass. Results of this study showed that seasonal inundation of the bypass resulted in an export of 14 to 37% of the combined floodplain plus river load of algal biomass downstream to the estuary although only 3% of the water passed through the seasonally inundated bypass. Although studies conducted to date have demonstrated that seasonal inundation of the Yolo Bypass floodplain results in increased primary production and increased loading of diatoms and other small algae to the lower river and estuary, results of the available studies are limited in their ability to quantity the relationship between the duration of floodplain inundation and the net contribution of algal production and delivery to the estuary. The data do, however, show that the response of algal production is relatively fast (days and weeks) in contributing to increased primary production and that shorter draining and filling cycles with multiple periods of inundation and draining within the bypass may further increase primary production (Schemel et al. 2004).

Results of studies conducted by Sommer et al. (2004) found that the density of zooplankton within bypass was not significantly different from zooplankton densities within the

Sacramento River. These studies did, however, show a rapid and substantial increase in densities of the dipteran, *Hydrobrobaenus saetheri*, and other terrestrial invertebrates in drift samples within the bypass after inundation. Similar results were reported by Benigno and Sommer (2008) who hypothesized that the insect eggs are present in the floodplain soils and that rehydration during initial inundation of the bypass triggers incubation, hatching, and emergence of the larvae into the water column where they drift downstream. Sommer et al. (2004) showed that within several weeks the density of dipteran larvae increased by approximately two orders of magnitude (0.01/m^2 in early February to over 1/m^2 by the end of February). Further, the densities of dipteran larvae were up to one order of magnitude greater in the floodplain when compared to the Sacramento River. Results of diet studies conducted on juvenile Chinook salmon (Sommer et al. 2001) showed that zooplankton and dipteran larvae were the two major components in the diet of rearing salmon. The increase in dipteran larvae within the Yolo Bypass floodplain would be expected to improve rearing conditions for juvenile salmon and other fish, resulting in greater growth rates than for those salmon rearing within the Sacramento River where prey densities were lower. Sommer et al. (2001) reported that juvenile Chinook salmon collected from the inundated Yolo Bypass were substantially larger than juveniles collected from the Sacramento River, which is consistent with the hypothesis that greater prey availability in the form of drift dipteran larvae within the bypass during inundation contributed to greater juvenile salmon growth. Based on these results it was concluded that invertebrate species, such as dipterans, may respond quickly to seasonal inundation of the floodplain (days or weeks), providing an increased load of organic material downstream into the lower river and estuary and provide a local food resource for foraging and increased growth of juvenile fish rearing within the inundated bypass.

Growth Rate of Juvenile Chinook Salmon

Information on the comparative sizes of juvenile Chinook salmon collected within the flooded bypass and adjacent locations within the Sacramento River in 1998 and 1999 (Sommer et al. 2000) showed that during the early period of rearing (e.g. February and early March) juvenile salmon were similar in size between the river and inundated bypass. Juvenile salmon showed evidence of increased growth rates within the inundated bypass beginning in approximately mid-March and continuing through April when inundation of the bypass was sustained through the early spring months. Results of coded wire tag studies and beach seine and rotary screw trap sampling within the bypass showed that on average residence time for juvenile salmon within the inundated bypass was approximately 30 days, although substantially shorter (4 days) and longer residence times (greater than 50 days) were also observed. These results suggest that, although short inundation of the bypass (e.g., days) may be sufficient to trigger incubation and emergence of dipteran larvae and stimulate primary production, longer periods of inundation (e.g., three weeks or more) may be required to provide sufficient time for fish such as juvenile Chinook salmon to rear and take advantage of increased prey availability, resulting in substantially improved growth rates and size when compared to those salmon continuing to rear in the Sacramento River and Delta.

Several factors in addition to the increase in prey availability within the inundated floodplain may contribute to increased growth rates of juvenile salmon inhabiting the inundated bypass. Water temperatures are typically higher within the bypass beginning in March compared to those in the Sacramento River (Sommer et al. 2000, 2001a, b). During spring air temperatures in the Sacramento Valley increase which, in combination with shallow water depths, large exposed surface area, and relatively low velocities, results in increased warming within the inundated bypass when compared to the Sacramento River. Increased seasonal water temperatures are thought to stimulate and accelerate growth of algae and insects within the inundated bypass which then serve as a prey base for juvenile fish rearing within the area. In addition, increased water temperatures during the spring (assuming that they are within the range considered to be suitable for juvenile fish) contribute to increased juvenile growth rates. Results of the previous investigations show that water temperatures within the inundated floodplain in February were similar to those in the Sacramento River (a response to generally cold air temperatures within the Sacramento valley during the winter months) within a trend of greater water temperatures within the inundated floodplain beginning in March and continuing through the period of inundation in the spring (typically receding before the end of April). Therefore, the biological repose to seasonal inundation of the floodplain would be expected to vary based on inundation during the early part of the period (e.g., February) when compared to inundation during the later part of the period (e.g., April).

The increased growth rate of juvenile salmon within the inundated floodplain when compared to the Sacramento River may also reflect differences in physical habitat characteristics. Sommer et al. (2001) found that the majority of juvenile Chinook salmon rearing within the inundated floodplain were inhabiting areas of reduced velocity (e.g., along channel margins, associated with structures and debris, immediately downstream of levees, etc.). The inundated floodplain is characterized by substantially shallower water depths, greater habitat complexity and diversity, greater channel margin habitat, and areas of reduced velocity that are more consistent with juvenile salmon rearing habitat preferences than habitat conditions in the mainstem river. For example, Sommer et al. (2001) estimated that during the February-March, 1999 inundation of the bypass that mean channel velocities were approximately 0.3 to 1 ft/sec compared to water velocities in the Sacramento River that were in excess of 3 ft/sec. Lower velocity habitat within the inundated bypass allows juvenile rearing salmon to exert less energy and, therefore, allocate a greater percentage of available energy toward growth. Sommer et al. (2004a) suggested that one metric for evaluating biological benefits of seasonally inundated habitat within the Yolo Bypass is a comparison of the area of habitat available with a water depth of <2 m (6 feet), which promotes higher productivity but is also associated with typically lower water velocities (Sommer et al. 2001a estimated that the inundated bypass provided approximately three times as much shoreline habitat as the adjacent Sacramento River). The relationship between surface area and flow within the bypass (Table ___) and results of observations and analyses by Sommer et al. (2001a, b, 2004a) show that there is a rapid increase in habitat area as a function of bypass flows up to approximately 4,000 cfs, after which the rate of habitat increase declines. When the entire bypass is inundated under even higher flows, water depth and velocity both increase resulting in reductions in both availability of high value habitat for juveniles and residence time, which promotes primary production.

Fish Passage for Multiple Species

Adult fish have been observed using the Yolo Bypass as an upstream migration corridor. These species include Chinook salmon, white sturgeon, splittail, and potentially other fish species (Harrell and Sommer 2003). Physical structures within the existing bypass such as the Lisbon Weir and Fremont Weir have been identified as impediments and potential barriers to successful upstream passage of fish through the bypass and into the Sacramento River. Two passage issues exist which include the passage impediment caused by existing structures when water is flowing from the Sacramento River into the bypass and false attraction of adults into the bypass by tributary flows when flow connectivity between the bypass and Sacramento River does not exist. Passage barriers and impediments and false attraction result in delays in migration and the increased risk of adult mortality. Observations at the Fremont Weir have shown that adult fish are vulnerable to increased legal and illegal harvest when they accumulate in the area immediately downstream of the weir. Efforts are currently underway to identify the design and operation of improved fish passage facilities that would contribute to reductions in delays and reduced risk of mortality associated with seasonal inundation of the bypass. The design and operations of fish passage facilities would be an integral component of modifications to the Fremont Weir. The level of mortality or sublethal impacts to various species of adult fish within the bypass, and the relationships between the frequency, magnitude, seasonal timing, or duration of inundation of the floodplain and the magnitude of potential adverse impacts to adult fish have not been quantified.

Negative Biological Effects

Water Quality

Increasing the frequency, magnitude, and duration of floodplain inundation within the Yolo Bypass has the potential to expose various species and lifestages of fish, zooplankton, insects, and other organisms to potentially toxic compounds. Exposure to mercury has been identified as a specific concern within the Yolo Bypass. The occurrence of mercury within the Sacramento River basin (Domagalski 1999 and other studies) has shown that concentrations may exceed state standards for protection of aquatic life. Concern has also been expressed regarding the methylation of mercury into a more toxic and bioavailable form associated with creation of stagnant wetland areas and decomposition of organic material. Additional issues of concern regarding water quality conditions include potential exposure to pesticides and herbicides resulting from seasonal inundation of areas used for agricultural production. The potential effects of exposure to these and other water quality constituents is a concern both locally within the seasonally inundated habitat as well as a result of the transport of these contaminants downstream into the lower Sacramento River and Delta. Studies are currently underway to provide additional information that can be used to quantitatively evaluate the potential risk and biological effects of contaminant exposure, as a function of duration and magnitude of exposure, on various aquatic species potentially inhabiting the seasonally inundated floodplain and downstream within the Delta.

Predation

Based on the observations of increased growth rates for juvenile salmon rearing within the inundated floodplain, Sommer et al. (2000, 2001a) hypothesized that survival of emigrating salmon inhabiting the bypass would be higher than survival rates for salmon emigrating through the lower Sacramento River. Sommer et al. (2000, 2001b) reported results of coded wire tag survival studies in which tagged juvenile salmon were released into the inundated bypass and Sacramento River. Survival estimates were based on tag recoveries downstream in Suisun Bay at Chipps Island. Results of these survival studies were inconclusive. Survival rates in 1998 were significantly higher for those salmon released into the inundated bypass while results for other years showed generally comparable survival rates between those salmon released into the inundated bypass and those released into the river. The factors that contribute to the difference in survival rates for salmon rearing in the inundated bypass among years are continuing to be investigated.

The variation in juvenile survival rates among years suggests that other factors, such as predation or stranding mortality, may be contributing to the net effect of the inundated bypass habitat on juvenile salmon. Sommer et al. (2001a) summarize information on the occurrence of various birds inhabiting the bypass including observations of heron and egrets that are predators on juvenile fish including Chinook salmon. Sommer et al. (2001a) concluded that although bird predation was occurring within the inundated bypass, the population level effect on juvenile salmon was expected to be low based on the low densities of wading birds relative to the inundated area and extent of habitat available for juvenile rearing fish. Similarly, a variety of native and non-native fish are known to inhabit the bypass (Sommer et al. 2001a) including predatory fish such as striped bass, largemouth bass, and Sacramento pikeminnow. Many of these predatory fish inhabit the bypass year-round within the toe drain and isolated ponds. As a result of the substantial fluctuation in aquatic habitat and the limited habitat available for predatory fish during a majority of time, there is no evidence of a predator population within the bypass that would result in population level mortality to juvenile rearing salmon or other fish.

Stranding

Stranding during flow recession represents a potential source of mortality for splittail, juvenile salmon, and other fish during periods of seasonal inundation within the bypass. Splittail typically spawn in March and April, depositing adhesive eggs on submerged vegetation and other substrates. During the period of egg incubation, the eggs are vulnerable to stranding and desiccation if water recession occurs before hatching. Feyrer et al. (2006) provide additional insight into managing floodplain inundation within the Yolo Bypass to benefit splittail reproduction.

Sommer et al. (2005) conducted an assessment of potential standing risk and the potential significance of stranding as a population level source of mortality for juvenile salmon. Results of observation and sampling within the bypass showed that areas with engineered water control structures contribute to a localized increase in the risk of stranding and mortality. Juvenile Chinook salmon standing was investigated within the inundated bypass during the flow recession stage in 1998, 1999, and 2000 by beach seining in various areas characterized by isolated ponds (general topographic features), contiguous water sources, earthen ponds associated with agricultural production and small soil levees, and concrete weirs. Results of statistical tests showed that the densities of juvenile salmon captured in isolated ponds and contiguous waters were not different. Stranding by concrete weir ponds was found to be significantly greater than the risk of stranding by earthen ponds. The rate of flow recession (ramping rate) observed by Sommer et al. 2005) was 1 cm/hr (approximately 0.4 inches/hr) is slow and would be expected to provide the opportunity for juvenile salmon and other fish to follow the flow recession and successfully migrate into the toe drain and downstream out of the bypass during flow recession. In addition, the general topography of the bypass is conducive to reducing the risk of fish stranding as a result of agricultural practices that tend to avoid creating areas of ponding and facilitate drainage to the toe drain. Based on results of these observations Sommer et al. (2005) concluded that there is a localized risk of mortality for juvenile salmon and other fish as a result of stranding, however, the mortality associated with stranding appears to be relatively low and can be consistent with management of habitat conditions within the bypass. For example, constructing fish passage faculties at constructed weirs and reducing or avoiding topographic features that contribute to increased stranding risk should be considered in design and operation of the seasonally inundated habitat.

Biological Effects Summary

Overall, the available information shows that increasing the frequency, duration, and magnitude of seasonal inundation of the Yolo Bypass has the potential to result in both positive and adverse impacts to covered fish, primary and secondary production, and other aquatic resources inhabiting the floodplain and downstream within the Delta. Results of the analysis indicate that on balance, there would be an expected net overall benefit to the Bay-Delta aquatic ecosystem, and covered fish species, as a result in increasing seasonal inundation of the bypass. Seasonal floodplain habitat is an important element in the functions of the river and Delta that has been substantially reduced within the watershed. Increasing connectivity between the Sacramento River and floodplain habitat would be expected to result in net environmental benefits. Seasonal flooding within the bypass would be most effective when in synchrony with the seasonal timing of naturally occurring hydrologic and seasonal events within the watershed. The duration of inundation would be expected to result in benefits to increased production of dipteran larvae, mobilization of organic material, and increased primary production in response to inundation lasting less than 30 days. Inundation of fewer than 30 days has the potential to result in stranding and mortality to incubating eggs and early larval stages for species such as splittail. Inundation lasting more than approximately 30 days in March and April would be expected to benefit splittail spawning and juvenile production. Short-duration inundation (fewer than 30 days) would be expected to result in only small benefit to juvenile salmon growth when compared to opportunities for rearing within the floodplain that extend longer than 30 days. Stranding and vulnerability to predation by birds and fish has been identified as a source of mortality within the floodplain habitat however these effects do not appear to be sufficient to result in population level impacts (resulting in a net population sink within the bypass). Modifications to the topography and existing weirs to improve upstream and downstream fish passage and reduce the risk of migration delays and stranding should be incorporated into future restoration management. Results of available studies have shown that biological and habitat benefits of seasonal floodplain inundation increase rapidly in response to increasing flows within the bypass but subsequently decline as flows increase to high levels (as a result of increased water velocities, increased water depths, and reduced residence times). The biological benefits also increase in response to the increased frequency and duration of floodplain inundation. Substantial biological benefits exist in response to floodplain inundation that appears to be in the range from approximately 2,000 to 4,000 cfs inflow which result in substantial increases in wetted surface area, shallow water habitat, and increased residence times that could be sustained for a longer period and occur more frequently than would occur with flows targeted at a level of 5,000 cfs or higher. Further analysis and quantification of positive and negative biological responses to seasonal inundation of the Yolo Bypass floodplain habitat will help refine specific operational objectives to the managed habitat.

Consultant's Recommended Operations

Here we recommend a set of operations based on hydrodynamic model output and anticipated benefits to covered fish species and other effects to the North Delta. These operations include the timing, duration, and frequency at which the Yolo Bypass would be inundated under controlled operations.

It is important to note that these recommendations apply only to non-flood stage conditions in the Sacramento River watershed. At flood stage, the Sacramento River and Yolo Bypass would be operated in accordance with flood safety regulations as defined elsewhere.

Timing

We recommend focusing the period of **January 1 to April 15** for operating the Fremont Weir to provide controlled inundation of the Yolo Bypass. Although natural hydrological timing is highly variable, the period before January 1 is generally too early to provide maximum benefits to a wide range of covered fish species because these species are not able to exploit this increased productivity. The period after April 15 would likely have great benefits to splittail spawning and rearing but, as water in the Bypass begins warming, non-natives begin spawning and can have negative impacts to native species. Further, agricultural uses of the Bypass generally begin in April and a flooded Bypass may be incompatible with these agricultural uses if inundation occurred in agricultural fields.

Fall-run Chinook salmon smolt densities in the adjacent reach of the Sacramento River are generally greatest between February and April (USFWS unpubl. data), although their peak emigration is closely tied with peaks in Sacramento River flow, which could occur even before January 1 or after April 15. Splittail year class strength is greatest with floodplain inundation between March and April (Moyle et al. 2004). Due to presence their in the vicinity of the North Delta between January 1 and April 15, juvenile winter-, spring-, and late fall-run Chinook salmon and steelhead could use the Yolo Bypass as rearing habitat, albeit to different degrees depending on their unique life histories. There is evidence that spring-run rear in a flooded Yolo Bypass (Sommer et al. 2005), although it is unknown to what degree other runs and species use the Bypass.

Juvenile delta and longfin smelt and green and white sturgeon, although they would not likely use the Bypass as rearing habitat, could benefit from productivity exported downstream from the Bypass to the rest of the Delta and bays. Although there is limited evidence that populations of these species are food-limited, individuals may be able to grow faster, thus obtaining higher survival and fecundity that could be exploited if limitations to other resources (e.g., habitat) are allayed. Longfin smelt likely to spawn and juveniles rear between November and May (Moyle 2002). Much of this rearing period is likely spent downstream of the Delta. Delta smelt primarily spawn between February and May and larvae rear in the Delta as late as June or until water temperatures exceed ~20°C (Bennett 2005). As with delta smelt, most rearing occurs downstream of the Yolo Bypass. Green and white sturgeon larvae are thought to inhabit the Delta year-round. As a result, populations of all four species could benefit from enhanced productivity exported from the Yolo Bypass.

Frequency and Duration

We recommend consideration of two scenarios:

1. Maximum Biological Benefits Scenario – A scenario that incorporates existing knowledge of biological benefits of frequency and duration of Yolo Bypass inundation to provide the greatest benefits to covered fish species.
2. Balanced Benefits Scenario – A scenario that incorporates benefits to covered fish species as in 1, but also considers other uses of the Yolo Bypass (e.g., agriculture, hunting, and wildlife viewing) and trade-offs of flows to benefit other North Delta corridors.

Maximum Biological Benefits Scenario

Because there are ecological benefits to any floodplain inundation duration period, this scenario recommends that the Fremont Weir be operated to allow **all uncontrolled flows into the Bypass of any duration** during the January 1 to April 15 period at the 17.53 ft NAVD 88 level. Further, there would be **no upper or lower limit to the flow rates into the Bypass. Activation of inundation periods would not be dependent on overtopping of the existing weir height of 33 ft (NAVD 88).** That is, flooding could occur earlier and at lower river stage than under the existing weir elevation.

This scenario is expected to provide high benefit to splittail spawning and rearing success and migration of fall-run Chinook salmon growth. This scenario is expected double the frequency of inundation at 3000 cfs (20,579 acres) of at least 30 days and nearly triple the frequency of inundation of at least 45 days (observed flow period data only [1984-2007]) (Tables 4 and 5). This scenario would also provide large opportunities for algal, dipteran, and terrestrial insect population growth and organic material inputs, much of which is predicted to be exported to the rest of the Delta and bays to benefit other covered species (Sommer et al. 2001).

Balanced Benefits Scenario

There are a number of other potential constraining factors of flooding the Yolo Bypass, including production of methylmercury; trade-offs of water for other flow splits in the North Delta, including Sutter and Steamboat Sloughs, a potential Deep Water Ship Channel bypass, the North Delta diversion facility, and bypass flows past the diversion facility; and other uses, including, but not limited to, wildlife observation, education, hunting, and farming. As a result, this scenario recommends scaling back from the Maximum Biological Benefits Scenario by reducing the duration and frequency of inundation of the Bypass to incorporate these other constraining factors. We recommend flooding the Bypass for **at least 30 but no more than 45 days** between January 1 and April 15. This duration would limit the exclusion of other uses of the bypass during this period. Because the growing season generally occurs in April through August, farming is expected to be minimally affected.

Unlike the Maximum Biological Benefits Scenario, **activation of inundation would be dependent on overtopping of the existing weir height of 33 ft (NAVD 88).** That is, inundation would not begin earlier or at a lower river stage than inundation under the existing weir configuration, but instead would extend the duration of existing inundation periods to 30-45 days. This minimizes effects of weir modification on terrestrial listed species because the natural flood events would have already reduced the quantity and quality of these species' habitat and/or food supplies. This displacement is expected to be the major effect on terrestrial species. This duration would also minimize production of methylmercury from the Bypass, which occurs when there is rapid wetting and drying of habitat.

We recommend that flows in the Bypass be **at least 2000 cfs but not more than 4000 cfs**, unless the river is at flood stage. Flows of <2000 cfs into the Bypass are not expected to provide sufficient benefits to warrant operation of the weir and may in fact cause detrimental effects, such as limited connectivity to the mainstem Sacramento River and stranding of splittail eggs and adult Chinook salmon and sturgeon; therefore, they are not recommended. The rate of additional acreage of inundated floodplain gained per unit flow rate is reduced above ~2000 cfs (Table 4). However, flows of 4000 cfs would inundate nearly half of the Bypass at a mean depth of 2.2 ft while still allowing over half the Yolo Bypass to be available for other uses during flooding (Table 4). Therefore, we recommend that flows that would spill into the weir above >4000 cfs be applied to other uses in the Sacramento River, such as Sutter and Steamboat Sloughs, a potential Deep Water Ship Channel bypass, the North Delta diversion facility, and bypass flows past the diversion facility.

Next Steps

Next steps include:

- Continued discussion and evaluation to refine and optimize the operational approach to the Fremont Weir and Yolo Bypass to reduce or eliminate negative effects of inundation.
- Develop quantified predictions of biological benefits based on hydrodynamic model output
- Incorporation of other parameters and conservation measures that may modify these operations.

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